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EFFECTS OF THE FEDERAL COLUMBIA RIVER POWER SYSTEM ON SALMON POPULATIONS

John G. Williams
Steven G. Smith
William D. Muir
Benjamin P. Sandford
Stephen Achord
Regan McNatt
Douglas M. Marsh
Richard W. Zabel
Mark D. Scheuerell

Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

INTRODUCTION

The construction and operation of the 31 Federal Columbia River Power System (FCRPS) dams contributed to the decline of anadromous salmon populations in the Columbia River basin and continues to affect them. While the dams provide about 60 percent of the Pacific Northwest region's hydroelectric generating capacity, supply irrigation water to more than a million acres of land, and store water to enhance flood control, they also block access to historic spawning areas or alter the migratory corridor leading to increased direct and indirect mortality. In addition to the FCRPS, human impacts from construction of hundreds of other dams, harvest, mining and dredging, and agricultural practices, have impacted various stocks of Columbia River basin anadromous salmon populations. Thus, ascribing effects of the FCRPS is complicated. Although many physical and operational changes have occurred since the completion of the FCRPS dams in an attempt to minimize impacts on anadromous salmon populations, and research has shown that increases in direct survival of salmonids migrants has occurred from the changes, the possibility exists that effects of the FCRPS only express themselves as indirectly downstream of the hydropower system. Determining the extent to which direct an indirect effects of the hydropower system negatively affect salmon populations, in the context of all other factors influencing salmon populations, is critical for defining additional measures needed by the FCRPS to assure salmon survival. Although we can measure direct survival and travel time of fish on an annual basis, inferences on delayed mortality often rely on long-term trends in return rates of adult fish, and these data are inherently variable. Thus, estimating the extent to which the FCRPS and the sum of all other human-induced activities affects salmon populations requires trying to tease out an understanding of direct and indirect impacts in concert with the natural variability in salmon populations. Direct knowledge of natural salmon variably generally does not exist, but the historical record provides some indications of its magnitude.

Historical Background

The size of all animal populations fluctuate. For salmon, we most often associate our activities to their population trends, and in many cases, rightly so. However, we generally lack knowledge of natural population fluctuations independent of human interactions. Despite a long Native American oral history in the Pacific Northwest, little information exists on the size and extent of salmon population fluctuations. Estimates of annual adult salmon returns to the Columbia River basin in the last couple of centuries have ranged from 7.4 to 8.8 million fish (Chapman 1986). Of these, Chapman (1986) estimated that spring and summer chinook salmon numbered 500-590 thousand, and 2-2.5 million, respectively. However, at the end of the last ice age (approximately 15,000 years before the present), glaciers covered most of the upper Columbia River and much of the Salmon River drainage (McPhail 1986). Thus, these salmon populations arose from extremely small stocks. Chatters et al. (1995)concluded that over the past 7,000 years, salmon production in the Columbia basin has varied tremendously with changes in climate. They speculated that average salmon populations were much lower approximately 3,500 BP compared to recent centuries, but higher 1,200 years before the present.

These speculations comport with recent findings of Finney et al. (2002) for Alaska sockeye salmon populations.

Anecdotal evidence indicates that natural variations in Columbia River salmon abundance also occurred over shorter time spans. Chance (1973) quotes from a number of early diaries that in 1811 and again in the late 1820s salmon populations from the middle Columbia River (between the confluence of the Snake River and Kettle Falls) were so low that settlers and native Americans relied on horse flesh for survival. Although Snake River basin salmon populations were also likely low at the same time, based on catch records for the Columbia River basin as a whole, all stocks rebounded to high levels near the end of the century. At that time, dramatic declines in Columbia River salmon populations began as a result of overfishing, exacerbated further beginning early in the 20th century by environmental degradation from mining, grazing, logging, water withdrawals for irrigation, and dams constructed on major tributaries for power production and water storage. Although stocks decreased, a signal of variability in run size still existed. The upriver run (above Bonneville Dam) of spring chinook salmon averaged 119,000 fish from 1940-1949 (with an average harvest rate of 60%), increased to 208,000 fish from 1950-1959 (with an average harvest rate of 60%), and decreased to 171,000 from 1960-1969 (with an average harvest rate of 39%) Status Report, Columbia River fish runs and fisheries - available at: http://www.dfw.state.or.us/ODFWhtml/InfoCntrFish/InterFish/crm.html#annual)

Impacts From Dams

Concerns about the potential impacts of the Federal Columbia River Power System (FCRPS) on anadromous fish were raised prior to the construction of Bonneville Dam (Griffin 1935). In fact, with the dam's completion, studies began in 1939 to estimate survival through turbines and spill for juvenile salmon passing the project to determine the dam's affect on juvenile salmon (Harlan B. Holmes, unpublished U.S. Bureau of Commercial Fisheries Report). Results from these studies and those by Schoeneman and Junge (1961)at McNary Dam in the mid-1950s led to concern about the probable impact that dams had on juveniles. As five additional dams were scheduled for construction on the mainstem Columbia and Snake Rivers, a Fish Passage Program within the Bureau of Commercial Fisheries (now NOAA Fisheries), began studies to determine the adaptability of salmon to new environments created by dams, effects of impoundments on fish migration, impacts to migrants from dam passage, and means to mitigate for effects.

Raymond (1979) provided the initial summary of changes in survival and travel time for yearling migrants that occurred during and after dam completion. In short, the 1966 to1968 average annual survival of wild yearling chinook salmon outmigrants from a trap on the Salmon River to Ice Harbor Dam averaged approximately 89% (Lower Monumental, Little Goose, and Lower Granite Dams were not yet completed) and the 1966 and 1967 (prior to completion of John Day) survival from Ice Harbor to The Dalles Dam averaged 64%. Combining these two estimates with an estimated survival between The Dalles and Bonneville Dam provided overall juvenile chinook salmon and steelhead survival estimates ranging between approximately 40-55% through what now constitutes the mainstem FCRPS dams (with 4 dams in place) (Williams et al. 2001). After completion of the system (with 8 dams in place), survival estimates for yearling chinook salmon and steelhead decreased to mean values of approximately 16 and 11%, respectively (but near 0 for both in the very low-flow year of 1977) (Williams et al. 2001).

Reservoirs behind dams increased travel time for juvenile migrants. Annual travel time estimates for fish were 10d (high flow) to 20 d (low flow) to migrate though the hydropower system with 4 mainstem dams in place (expansion of data from (Raymond 1979), but after completion of all 8 dams, annual travel time estimates ranged from 15d (high flow) to 40 d (low flow). Concurrent with research documenting direct impacts of the dams on fish, other researchers worked on means to mitigate for the dam's impacts. This research led the U.S. Army Corps of Engineers (COE) to construct juvenile bypass systems at dams, modify spillways, and implement a transportation program to collect fish at upstream dams and barge them to a release site below Bonneville Dam.

Despite these efforts, by the early to mid-1990s, stocks had not recovered. As a consequence, 12 of 16 Columbia River basin Evolutionarily Significant Units (ESUs) (Waples 1991) were listed as threatened or endangered under the Endangered Species Act (ESA) (April 22, 1992: 57 FR 14653).

The PATH Process

To provide information needed to write Biological Opinions associated with the stock listings, and develop estimates of FCRPS impacts, in 1995, NOAA Fisheries (NMFS) created the Plan for Analyzing and Testing Hypotheses (PATH). A summary of the PATH process based on a paper by Marmorek and Peters (2001) follows.

A group of approximately 30 scientists worked for nearly 5 years to develop analyses to explain the impact of the FCRPS on anadromous fish stocks above Bonneville Dam.. PATH scientists identified two key uncertainties that most strongly affect survival and recovery potentials of Snake River spring/summer and fall chinook salmon: delayed mortality of non-transported fish, and the relative post-Bonneville survival of transported fish compared to post-Bonneville survival of non-transported fish (designated as "D").

Delayed mortality was defined as any mortality occurring outside the juvenile migration corridor not accounted for by the other terms used in the PATH life cycle models (such as, productivity and carrying capacity, mortality in reservoirs and at dams, and estuarine/ocean mortality affecting all salmonid populations). As the observed historical patterns in delayed mortality were linked with several possible causes, PATH formulated three alternative hypotheses concerning delayed mortality and the possibility of actions within the FCRPS to decrease it:

a. “Hydro” – delayed mortality resulted from adverse effects to smolts from migrating through the 8 mainstem dams of the FCRPS. Removal of dams in the Snake River would eliminate delayed mortality.
b. “Regime shift” – delayed mortality follows a 60-yr cycle related to long-term cycles in ocean conditions. No FCRPS actions will directly reduce delayed mortality, but delayed mortality will eventually dissipate when ocean conditions improve.
c. “Stock viability” – delayed mortality resulted from processes not affected by any FCRPS action or regime shift. Stocks will remain low due to interactions with hatchery fish, the presence of diseases such as Bacterial Kidney Disease, or reduction in nutrients associated with historical declines in spawning stock.

In the PATH models, “D” represented an annual value of the differential survival downstream of Bonneville Dam for transported fish compared to non-transported fish. If D approached 1.0, it indicated that transportation of juveniles avoided all losses that migrants would have incurred had they migrated downstream through the hydropower system. On-the-other-hand, low values of “D” indicated that transportation did not provide full mitigation for losses at dams; that is, transported fish incurred more mortality sownstream of Bonneville Dam than did non-transported fish. Further, if a low enough value of “D” existed it explained historical patterns of stock productivity without the need to require delayed mortality to explain changes in productivity.

Many PATH participants felt that delayed mortality existed; however, consensus among the group that it did, or causes as to why, was never reached. Arguments for the existence of delayed mortality and its linkage to the FCRPS were made by Schaller et al. (1999, 2000), Deriso et al. (2001), Petrosky et al. (2001), and Budy et al. (2002). Zabel and Williams (2000) suggested that differences in productivity could have occurred as a result of differences in underlying stock responses to changing ocean conditions. Subsequent to PATH, Levin and Tolimieri (2001) and Levin(2003)found that chinook salmon populations used in the PATH life cycle models, Snake, Upper Columbia, and middle Columbia, had different productivity, and productivity varied between different time periods, but not consistently with changes in ocean conditions.

Evaluations of Stocks Subsequent to PATH

Due to perceived complexity of PATH products by some Northwest Fisheries Science Center scientists not involved with PATH, a matrix model was developed in mid- to late 1999 to evaluate the status of listed Snake River spring-summer chinook salmon stocks. The results of the matrix modeling process indicated that little room to increase stock productivity existed within the migration corridor of the FCRPS because of past improvements made at dams. Results indicated that factors currently driving productivity occurred in the freshwater spawning and rearing areas and in estuary/early ocean residence (Kareiva et al. 2000). The matrix model set a value for “D” at 0.7, and used a range of values for delayed mortality.

Concurrent with matrix-modeling efforts, other NWFSC staff developed draft "White Papers" to summarize knowledge about FCRPS impacts to stocks. After considering comments based on regional review, final versions of the "White Papers" were posted on the NWFSC website: http://www.nwfsc.noaa.gov/publications/whitepapers/index.cfm. The "White Papers" covered the following:

1) "Passage of Juvenile and Adult Salmonids Past Columbia and Snake River Dams,"
2) "Predation on Salmonids Relative to the Federal Columbia River Power System,"
3) "Salmonid Travel Time and Survival Related to Flow in the Columbia River basin," and
4) "Summary of Research Related to Transportation of Juvenile Anadromous Salmonids Around Snake and Columbia River Dams".

In developing the NMFS 2000 FCRPS BiOp, the Biological Effects Team reviewed and analyzed fish passage assumptions used by NMFS in earlier fish passage modeling exercises, those developed in the PATH process, fish passage information contained in the four "White Papers", and the most recent empirical data to determine the fish passage parameters for input into the Simulated Passage (SIMPAS) model. To develop a new BiOp, NOAA Fisheries needs an update on impacts of the FCRPS on ESA listed salmonids in the Columbia River basin. In this Tech Memo we provide an update on hydropower system survival for listed juvenile and adult salmon through the mainstem Snake and Columbia River dams (to the extent data are available), impacts of transportation, flow effects on survival and travel time, and overall effects of FCRPS operations on adult returns. We focus primarily on Snake River spring-summer chinook salmon, as these fish migrate through the entire FCRPS mainstem dam complex and we have the most data about these stocks. Fewer data exist for all other stocks, so we either provide incomplete information or make inferences where we deem reasonable.

Returns of many listed Columbia River salmon stocks in the last several years have far exceeded numbers seen in recent decades. Thus, we also provide associations between direct FCRPS impacts to these changes in adult returns. Again, we do this most effectively for Snake River spring-summer chinook salmon, as we have the best measure of their population fluctuation over time. For other stocks, we must rely on changes in combined wild and hatchery adult returns to dams, as reliable estimates of wild adult returns and juvenile smolts do not exist.

The following sections provide summaries of methods and results from work contained in recent annual reports to the COE and BPA, or in peer-reviewed literature. We direct readers who want additional information to those sources. In a few cases, some of our work is not readily available as it is contained in manuscripts under review or "in press". We will provide additional details of this information, on request.

METHODS

Snake River Spring-summer Chinook Salmon SARs (Non-tagged Population)

Smolt-to-adult return rates (SARs) provide a measure of survival that encompasses the smolt migration, estuary/ocean, and adult return stages. It is calculated by dividing returning adults from a single brood year by smolts from the brood year. If SARs are calculated over an extended number of years, they can provide an index of temporal variability in stock productivity. We estimated recent smolt-to-adult return percentages (SARs) from Lower Granite Dam, and to compare them with earlier years adjust them for downstream harvest. WE then used these estimates to compare to estimates of SARs (catch plus escapement) to the upper Snake River dam in earlier years. In brief, from Petrosky et al. (2001) we used estimated wild adult (1-, 2-, and 3-ocean fish) returns from 1964 to 1996 (we adjusted 1993 to 1996 1-ocean fish for estimated additional returns to Oregon) and harvest rates from 1964 to 1999. We used Raymond (1988) for estimates of smolt abundance between 1964 and 1984. We derived estimates for wild smolts from 1993 to 2003 by expanding the daily collection of wild fish at Lower Granite Dam (http://www.fpc.org/smoltqueries/HistoricDailyData.asp), by the daily estimates of detection efficiency (derived with (Sandford and Smith 2002)methodology) of wild smolts at the dam for each year. For smolt years 1998 to 2002, we adjusted smolt estimates by an estimated percentage of non-clipped hatchery fish arriving at the dam not identified as hatchery origin. This adjustment decreased numbers of wild smolts by 3, 8, 6, 11, and 1% for smolt years 1998 through 2002, respectively. We estimated smolt abundance from 1985 to 1993 based on a Beverton-Holt curve generated from estimated numbers of smolts from 1964 to1984 and 1994 to 2003 ($R^2 \cong 0.80$), and the number of wild fish passing the upper Snake River dam 2 years earlier. We derived the estimated wild adult returns to Lower Granite Dam from 1997 through 2003 from annual fish counts of spring-summer chinook salmon reported to have passed the dam. Fish counters at the dam enumerated fish as they passed through the counting window and assigned them to either a group with adipose fins (ostensibly wild fish) or a group without adipose fins (known hatchery fish with fins clipped as juveniles). We adjusted the clipped hatchery fish returns by an estimated return rate of non-clipped hatchery juveniles. We then subtracted the corrected hatchery count from the total adult return to derive the wild fish estimate.

To separate adult returns into the respective 2- and 3-ocean component, we used an iterative process to estimate 3-ocean returns each year, starting with the 1997 return year. The total wild return for the 1994 outmigration was estimated by expanding the wild jack return (based on adjusted fin-clipped fish) in 1995 and 2-ocean return in 1996 from (Petrosky et al. 2001) by their estimated percentage of the return based on wild PIT-tagged fish estimated to have passed Lower Granite Dam in 1994. Subtracting the estimated jack and 2-ocean returns from the total provided an estimate of the 3-ocean returns in 1997. This number subtracted from the estimated total wild adult return in 1997 provided an estimate of the wild 2-ocean component. Thus, with the 1996 wild jack estimate and the just derived 1997 wild 2-ocean component, we could estimate the number of wild 3-ocean fish returning in 1998 based on the percentage of PIT-tagged adults that returned from the total returns of PIT-tagged fish from the 1995 outmigration. We repeated this process to estimate the 2- and 3-ocean components from each adult return year to Lower Granite Dam. Finally, to account harvest rates in the Columbia River that varied between 0 and 40%, we expanded adult returns to the uppermost Snake River dam for the period between 1964 and 1999 based on estimated Columbia River harvest rates Petrosky et al. (2001). We expanded adult returns for 2000 to 2003 based on unpublished harvest rates (Peter Dygert, NOAA Fisheries, personal communication).

Population Trends for Other Unmarked Stocks

We did not have detailed data for stocks other than wild Snake River spring-summer chinook salmon. To compare returns for other stocks to those for wild Snake River spring-summer chinook salmon, we used counts of adult fish at dams (data downloaded from the DART web site: http://www.cqs.washington.edu/dart/adult.html). We used Bonneville Dam for the composite wild steelhead run, Ice Harbor Dam for the wild Snake River steelhead run, and Priest Rapids Dam for the composite wild/hatchery spring chinook salmon run. For the natural-origin Snake River fall chinook salmon run we used updated (unpublished) adult escapements over Lower Granite Dam developed by NWFSC scientists for use in status reviews. For each stock grouping, we developed a ratio of the median return from 2001 to 2003 (2000 to 2002 for Snake River fall chinook) to the median return between 1990 and 1999. We then compared these ratios to a ratio of the median SARs from the 1988 to 1997 and 1998 to 2000 outmigrations for wild Snake River spring-summer chinook salmon.

PIT-tagged Fish Used for Analyses

PIT tagging juvenile salmonids began on a small scale in 1987 and has expanded tremendously since that time, although not homogeneously throughout the Columbia River basin. Between 1989 and 2001, the majority of tagged fish were Snake River spring/summer chinook salmon. The fish tagged do not always represent the run or rearing type for the general population of a species. Some studies PIT tag fish as they pass discrete points along the migration corridor, while others tag fish only in certain natal streams or hatcheries, or tag the same number in each stream or hatchery regardless of the total number of fish available. This leaves other streams or hatcheries unmarked or under represented in the sample population. Twenty different organizations have PIT tagged fish in the basin. By far, NOAA Fisheries has PIT-tagged the majority of fish (ca. 5.2 M) , followed by U.S. Fish and Wildlife Service (USFWS) (ca.1.1 M), and Idaho Fish and Game (IDFG) (ca. 1.0 M), to as few as ca. 235 by Columbia Intertribal Fisheries Commission (CRITFC) (Table 1).

Table 1. Number of juvenile salmonids PIT-tagged in the Columbia River basin, 1987-2003.

Outmigration year	Upper Columbia River[a]	Snake River	Middle Columbia River[b]	Lower Columbia River[c]	Willamette River
1987	7,673	2,619	-	-	-
1988	-	19,728	25,088	-	-
1989	4,998	92,254	22,894	-	-
1990	7,857	66,804	22,099	1,700	-
1991	6,644	70,462	32,613	724	-
1992	11,021	66,144	30,645	1,002	-
1993	24,326	132,409	29,693	733	-
1994	33,916	335,845	1,853	721	1,775
1995	34,982	514,551	-	-	-
1996	46,213	373,356	3,044	2,980	-
1997	40,153	458,881	107,685	10,708	-
1998	147,133	589,815	200,595	12,666	-
1999	168,593	763,014	477,897	18,336	3,429
2001	214,688	561,453	178,734	33,025	7,791
2002	613,296	858,240	223,181	59,511	9,597
2003	1,023,730	907,460	121,805	124,748	3,927
Total	2,385,223	5,813,035	1,477,826	266,854	26,519

[a] drainage above the confluence with the Yakima River (above RKm 539)
[b] drainage between the confluence with the Wind and Yakima Rivers (between RKm 252-539)
[c] drainage from the Wind River to the ocean (below RKm 252)

Juvenile Reach Survival Estimates for PIT-tagged Fish

General

All mainstem dams on the lower Snake and Columbia Rivers, except The Dalles Dam, have juvenile fish bypass facilities (Figure 1.) (Matthews et al. 1977). These systems use screens to divert migrant smolts away from turbine intakes and into gatewells. Fish pass out of gatewells through orifices into a collection channel, where they pass directly to a pipe that discharges them to the tailrace, or they pass through a dewatering section leading to sampling facilities. With the exception of Ice Harbor Dam, all bypassed fish pass through detectors that identify nearly 100% of PIT-tagged fish. PIT-tagged fish detected in the facilities at Lower Granite, Little Goose, Lower Monumental, and McNary dams ("collector", or "transport dams") can get routed to raceways for loading into trucks or barges for transportation, or they get routed back to the river via a slide gate (Marsh 1999). The most downstream site for detections of PIT-tagged juvenile fish exists in the Columbia River estuary between RKm 65 and 84, where a 2-boat trawl tows a PIT-tag detector (Ledgerwood 2000).

We estimate survival probabilities for juvenile migrant fish from PIT-tag detection histories. The estimated survival probability for a particular segment of the migration corridor is a group-level statistic, interpreted as an estimate of the proportion of the group that survived the segment. Collections of PIT-tagged fish are defined as a "group" for survival estimation in three primary ways: (1) fish tagged at the same time and released as a batch at a single point (typical for studies planned to address a specific research question, and for daily samples of fish collected at a smolt trap); (2) tagged fish held together in a holding facility for a period of time and then released from the same point over a short period of time (typical for volitional releases from hatcheries); (3) tagged fish released at various sites upstream from a particular dam, then grouped according to the date on which they were detected at the dam and returned to the tailrace (typical for attempts to gather a time series of survival estimates throughout the migration season). For estimates and analyses reported here, groups sometimes contain both hatchery and wild fish, or we treat the two rearing types separately. In all cases, a "group" of fish includes fish of only one species.

However the group is defined, survival probabilities are estimated using the collection of records of detection ("detection histories") for every individual fish in the group. Because each PIT tag is uniquely coded, and because the portion of detected fish that are returned to the river allows detection multiple times, we analyzed the detection history data using a multiple-recapture model for single release groups. We use a model originally presented and investigated by Cormack (1964), Jolly (1965), and Seber (1965), known as the "CJS Model" or "Single-Release (SR) Model." Use of this model for survival estimation using PIT-tagged fish was first described in detail by (Skalski 1998).

The minimum requirements for survival estimation using the SR are the release of a group of PIT-tagged fish at the beginning of the river segment of interest, one detection site where at least some of the detected fish are returned to the river for subsequent detection opportunities, and at least one detection site farther downstream. If there were only one detection site downstream from the release site, or if all detected fish at the first site were removed from the river, then it would be impossible to distinguish failure to detect a passing (surviving) fish from mortality before arrival at the detection site (i.e., survival probabilities could not be estimated separately from detection probabilities). Fish detected downstream from the first detection site constitute a sample of the fish that were alive at the first site; they are used to estimate the proportion of fish passing the first site that were detected (detection probability). Having obtained the estimate of the detection probability, we can then estimate the survival probability. When there is a series of detection sites with return-to-river capabilities, survival estimates are possible from release to the first site, then between each pair of consecutive sites, except that the inability to distinguish mortality from the failure to detect a surviving fish always precludes estimation between the last two sites.

In 1993, when a study specifically designed to estimate migrant smolt survival began, PIT-tag detectors were operational only at Lower Granite, Little Goose, Lower Monumental, and McNary Dams. Only Lower Granite and Little Goose Dams were equipped with slide gates to divert PIT-tagged fish from the bypass system back to the river. Under this configuration, estimates of survival could be calculated for a group of fish from the point of release above Lower Granite Dam to the Lower Granite Dam tailrace and from Lower Granite Dam tailrace to Little Goose Dam tailrace. PIT-tag detectors and slide-gates have been added gradually to other dams since 1993 (in a downstream direction). Under present conditions, provided sufficient fish from the group are detected by the estuarine trawl, survival can be estimated for any group of PIT-tagged fish from any release point upstream from Bonneville Dam to the tailrace of Bonneville Dam.

All survival estimates presented are from point of release (or the tailrace of a dam) to the tailrace of a dam downstream. All survival and detection probability estimates were computed using the statistical computer program SURPH ("Survival with Proportional Hazards") for analyzing release-recapture data, developed at the University of Washington (Skalski 1993, Smith 1994).

Assumptions of Single-Release Model

Using the SR Model, the passage of a single PIT-tagged salmonid through the hydropower system is modeled as a sequence of events. Examples of such events are survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam, and detection at Little Goose Dam. Each event has an associated probability of occurrence. The detection history is the record of the outcomes of the events. (As previously noted, the detection history is an imperfect record of outcomes; if the history ends with one or more "zeroes," we cannot distinguish mortality from survival without detection). The SR Model represents detection history data for a group of tagged fish as a multinomial distribution; each multinomial cell probability (detection history probability) is a function of the underlying survival and detection event probabilities. Estimates of survival probabilities under the SR Model are random variables, subject to sampling variability. When true survival probabilities are close to 1.0 and/or when sampling variability is high, it is possible for estimates of survival probabilities to exceed 1.0. For practical purposes, estimates should be considered equal to 1.0 in these cases.
Three key assumptions lead to the multinomial cell probabilities used in the SR Model:

A1) Fish in a single group of tagged fish have common event probabilities (each conditional detection or survival probability is common to all fish in the group).

A2) Event probabilities for each individual fish are independent from those for all other fish.

A3) Each event probability is conditionally independent from all other probabilities.

For a broader description of these assumptions and how to test them, see Burnham et al. (1987)and Zabel et al. (2002, Appendix 1).

To varying degrees, these assumptions are inevitably violated for any particular group of migrating salmonids. Reasons that the assumptions might not strictly hold are: variation in fitness among fish in a group; variation in migration rate means, for example, that individuals from the same group may pass a dam under different conditions; inherent traits or behavioral preferences might make detection of some fish more likely at all dams.

Violations of model assumptions can cause bias in resulting parameter estimates. However, known causes and degrees of SR Model violations for migrating juvenile salmonids have been investigated, and have been shown to cause minimal bias e.g. from (Skalski 1998). Studies are planned and analyses are designed to minimize the potential of significant bias due to violation of model assumptions.

Hatchery and Trap Release Groups

Seven hatcheries in the Snake River Basin released PIT-tagged fish each year between 1993 and 2003: Dworshak, Kooskia, Lookingglass, Rapid River, McCall, Pahsimeroi, and Sawtooth. For each hatchery each year we identified the group of PIT-tagged fish that was most representative of the hatchery's production release. For these groups of yearling chinook salmon and steelhead we calculated estimates of survival from release to the tailrace of Lower Granite Dam. Many of these groups were released as a batch on a single occasion; others are released volitionally over a period of days from hatchery ponds or raceways.

We also estimated survival from release to Lower Granite Dam for wild and hatchery PIT-tagged yearling chinook salmon and steelhead from the Salmon River (White Bird) and Snake River smolt traps. While fish are tagged and released nearly daily from these traps, daily groups rarely have sufficient data to calculate reliable survival estimates. For traps, then, we pooled all fish tagged and released between the beginning of operations in the spring and 31 May.

Annual Average Survival Estimates for Spring Migrants From Lower Granite and McNary Dams

Between 1993 and 2003, hatchery and wild yearling chinook salmon and steelhead have been tagged in varying numbers at various locations upstream from Lower Granite Dam. Studies have also been conducted involving fish collected and tagged at Lower Granite Dam and then released into the tailrace. For survival estimation each year, we create daily "release groups" from Lower Granite Dam by combining fish tagged at the dam and released into the tailrace with previously tagged fish that were detected at the dam and returned to the tailrace the same day. For each daily group, detection data downstream from Lower Granite Dam are usually sufficient to calculate SR-Model survival estimates between Lower Granite and Little Goose dams, between Little Goose and Lower Monumental dams, and between Lower Monumental and McNary dams. If data for a daily group are not sufficient, we pool adjacent days until estimates to McNary Dam are possible.

To obtain survival estimates downstream of McNary Dam, we regroup fish into daily groups at McNary Dam, using the same methods described above for Lower Granite Dam. Detection data downstream from McNary Dam are usually not sufficient for each daily group. Therefore, we pool the daily groups into weekly groups. For weekly groups leaving McNary Dam, we estimate survival between McNary and John Day dams, and between John Day and Bonneville dams.

Using these methods, we obtain estimates for particular river sections from multiple groups of PIT-tagged fish throughout each migration season. Annual average estimates for these river sections are obtained using a weighted mean as they provide the most unbiased survival estimates (Muir et al. 2001).

Annual Average Survival Estimates Through the Entire Hydropower System

For Snake River yearling chinook salmon and steelhead, we estimated the annual mean survival probability from the head of Lower Granite Dam reservoir to Bonneville Dam tailrace. We calculated this estimate by multiplying three components: the estimate of survival from the Snake River Trap (near the head of the reservoir) to Lower Granite Dam (hatchery and wild fish pooled); the weighted mean survival estimate for daily groups from Lower Granite Dam tailrace to McNary Dam tailrace; and the weighted mean estimate for weekly groups from McNary Dam tailrace to Bonneville Dam tailrace.

Data Sources and Limitation

Information for chinook salmon and steelhead PIT-tagged and released in the Columbia River basin was obtained from the regional PTAGIS database (information available at www.psmfc.org . From these, we grouped fish by migration year, species, run, rearing type, release site, and in some cases by time periods.

Sometimes, due to small or zero sample sizes at the most downstream observation sites caused by very poor survival to those sites, and/or low detection rates at those sites, survival for some cohorts for the MCN-JDA and/or JDA-BON reaches was not estimated or alternate survival estimates were calculated by using the pooled estimate for a particular species-run-rearing type. In particular, estimates to BON were not calculated for mid-Columbia and Yakima groups until 2001 and 2002, respectively.

Our estimates were calculated only using information available from PTAGIS. We were certainly not aware of all the various experimental caveats and details involved in the studies for which fish were tagged. Thus, although we used available PIT-tagged fish for survival estimates, we recognize that not all fish were necessarily released for the single purpose of estimating downstream reach survival. Therefore, some survival estimates, even if mathematically "correct," may not reflect or represent the true survival of the untagged population to which inference is intended.

Piscivorus Bird Predation

All PIT-tagged fish that survived to the McNary pool were subject to predation by piscivorus birds residing on various islands, including Caspian terns, double-crested cormorants, gulls, and pelicans. The bird colony locations included, but were not limited to, Richland Island, Island 18, Foundation Island, Badger Island, and Crescent Island (all islands located in the McNary Dam reservoir - mostly above the confluence with the Snake River). Predation also occurred from birds residing in various locations below MCN to the mouth of the Columbia River and much of this information is contained in another Tech Memo on the role of the estuary in the recovery of Columbia River basin salmon and steelhead. We calculated the proportion of PIT-tags obtained from these islands for the cohorts detailed above. This provided a minimum mortality estimate of bird predation which can be used to assess relative impacts between various cohorts. Nearly all the PIT-tag information needed for this assessment was obtained by NOAA Fisheries researchers and is available from the PTAGIS database. We estimated only the proportion of fish released from hatcheries and dam that were detected on bird colonies as we could not estimate the proportion of fish alive upstream of the McNary Dam pool, since no PIT-tag estimates of survival to the head of MCN pool are available.

SARs for PIT-tagged Fish

To estimate SARs for PIT-tagged Snake River fish as measured from Lower Granite Dam as smolts to Lower Granite Dam as adults, we followed the methods in Sandford and Smith (2002). We estimated how many fish passed the dam on each day of the migration season and totaled the daily estimates. To get each day's estimate, we used the following process:

1) For fish detected on a given day at Little Goose Dam that had previously been detected at Lower Granite Dam, tabulate according to their detection (passage) day at Lower Granite Dam;

2) For fish detected on the same day at Little Goose Dam that had NOT previously been detected at Lower Granite Dam, assign them to their estimated "non-detection passage day" at Lower Granite Dam, assuming that their distribution over days at Lower Granite Dam was proportionate to that of fish detected at Lower Granite Dam;

3) Repeat this process for all days of detection at Little Goose Dam;

4) Sum all these detected and non-detected fish for a given day at Lower Granite Dam;

5) Estimate that day's detection probability by calculating the proportion of detected fish to the total of detected and non-detected fish (after making an adjustment for fish transported at Lower Granite Dam); and

6) Divide the total detected number at Lower Granite Dam on that day (bypassed and transported) by the estimated detection probability to get an estimated daily total.

Formally, this process is referred to as the Schaefer method. We modified the method slightly for estimates in the tails of the passage distribution where the above process wasn't applicable (e.g., for days when no detections occurred at Little Goose Dam)

We then estimated SARs for various "detection-history categories", in particular for fish transported from Lower Granite, Little Goose, Lower Monumental, or McNary Dams, for fish bypassed back to the river one or more times at these dams, and for fish never detected at these dams. To do this, we developed daily passage estimates at Lower Granite Dam using the following process:

1) We estimated for each daily Lower Granite passage group the probabilities of detection at Little Goose, Lower Monumental, and McNary Dams using the Cormack-Jolly-Seber survival model (Cormack 1964, Jolly 1965, Seber 1965).

2) We multiplied the estimated daily Lower Granite Dam total by the appropriate detection and transport probabilities. For example, for the detection-history category "not detected at Little Goose Dam and then transported from Lower Monumental Dam", this is equivalent to multiplying the Lower Granite Dam daily estimate by (1 - probability of Little Goose Dam detection) times (probability of Lower Monumental detection).

3) We summed the estimates for all daily groups to get total smolts in each detection-history category.

Next we calculated SARs. For a given detection-history category, this was the ratio of the observed number of adults in the category to the estimated number of smolts in that category.

Finally, we estimated the precision for the estimated SAR using bootstrap methods where the individual fish information (i.e., detection history, detection dates, and adult return record) and the entire estimation process were bootstrapped 1,000 times. Confidence limits were generated from the bootstrapped estimates.

Flow/travel Time Estimates for PIT-tagged Fish

Travel times were calculated for yearling chinook salmon and steelhead from 1) Lower Granite Dam to Little Goose Dam (60 km), 2) Little Goose Dam to Lower Monumental Dam (46 km), 3) Lower Monumental Dam to McNary Dam (199 km), 4) Lower Granite Dam to McNary Dam (225 km), 5) Lower Granite Dam to Bonneville Dam (461 km), 6) McNary Dam to John Day Dam (123 km), 7) John Day Dam to Bonneville Dam (113 km), and 8) McNary Dam to Bonneville Dam (236 km). Travel time between any two dams was calculated for each fish detected at both dams as the number of days between last detection at the upstream dam (generally at a PIT-tag detector close enough to the outfall site that fish arrived in the tailrace within minutes after detection) and first detection at the downstream dam. Travel time included the time required to move through the reservoir to the forebay of the downstream dam and any delay associated with residence in the forebay, gatewells, or collection channel prior to detection in the juvenile bypass system.

Migration rate through a river section was calculated as the length of the section (km) divided by the travel time (days) (which included any delay at dams as noted above). For each group, the 20th percentile, median, and 80th percentile travel times and migration rates were determined.

The true complete set of travel times for a release group includes travel times of both detected and not-detected fish. However, using PIT tags, travel times cannot be determined for a fish that traverses a river section but is not detected at both ends of the section. Travel time statistics are computed only from travel times for detected fish, which represent a sample of the complete set. Non-detected fish pass dams via turbines and spill; thus, their time to pass a dam is typically minutes to hours shorter than detected fish passing to the tailrace via the juvenile bypass system.

Transportation Evaluations

We evaluated the efficacy of transportation two ways. First, we compared the return rate of transported fish to the return rate of control fish that migrated volitionally through the hydropower system. This provided a *T:I* ratio, simply the ratio of the return rates of transported (*T*) fish and non-transported (inriver) migrants (*I*). A value greater than 1 indicates transportation was beneficial. We also evaluated D, defined as the ratio of post-Bonneville Dam survival for transported fish to that of the non-transported fish. If D < 1, then fish released from barges survived at a lower rate compared to a non-transported migrants. We provide details of the methodology below.

Snake River Yearling Migrants

We based our evaluation of transportation on comparisons of return rates from fish PIT-tagged as juveniles that migrated through the hydropower system versus fish collected and transported. We based most of our evaluations on fish from two general sources. We utilized fish PIT-tagged for the Comparative Survival Study (CSS) above Lower Granite Dam that passed through sort-by-code systems installed in bypass systems at collector dams (Lower Granite, Little Goose, and Lower Monumental Dams on the Snake River and McNary Dam on the Columbia River) and were specifically released to evaluate transportation. Of the fish collected, some were automatically diverted to raceways for transportation, while others were returned to the river to allow estimation of survival for the downstream migrants. We also PIT-tagged juvenile fish collected at Lower Granite Dam, some of which we released into raceways for subsequent transportation and others we released to the tailrace of the dam. Finally, as slide gates are not 100% effective at diverting PIT-tagged fish back to the river, some non-designated fish PIT-tagged above Lower Granite Dam get transported. We evaluated these fish where possible, but due to quite small sample sizes, SARs for these have large confidence bounds.

Groups of fish PIT tagged above and at Lower Granite Dam each have advantages and disadvantages for evaluating transportation. For fish PIT tagged above the dam, fish collected at Lower Granite Dam presumably represent the untagged population collected at the dam, while fish not collected (therefore not detected) represent the unmarked population of fish that passed the dam through turbines and spill. However, for fish tagged above the dam, we do not have a direct measure of how many non-detected fish pass the dam (we can estimate this). Moreover , when an adult returns that was not detected as a juvenile, we do not know when the fish passed the dam as a juvenile. For groups of these fish, we can only estimate annual transport to non-transport ratios (T/I) and annual values of D. For fish PIT tagged at Lower Granite Dam, no "true" controls exist because all fish for studies are first collected from the juvenile bypass facilities at Lower Granite Dam. Thus, no sample exists that represents untagged, uncollected fish. However, tagging at dams has some advantages. After release, we know the number of downstream migrants that subsequently represent the untagged population. Further we can estimate temporal SAR trends for transported and non-transported fish. From this we can estimate temporal D trends.

Upper Columbia River Subyearling Chinook Salmon

Prior to 2000, only Lower Granite Dam had equipment installed capable of detecting PIT-tagged adult migrants. Thus, to evaluate the efficacy of transportation at McNary Dam (after construction of the new juvenile bypass/collection facilities in 1994) required methods used previously to evaluate transportation. In 1995 and 1996, approximately 110,000 and 120,000 juvenile subyearling chinook salmon, respectively, were collected in the juvenile bypass facility at the dam and coded-wire tagged (CWT). Fish were tagged 5 days/week in proportion to the daily collection. Each day approximately 60% of the fish were released to the tailrace of the dam through the bypass facility pipe. The other 40% of the fish were transferred into barges and released downstream of Bonneville Dam. Evaluations of the transported to non-transported ratios (T/I) was based on CWT recoveries from fisheries and hatcheries.

Computing D

PATH-derived D

The PATH (Marmorek et al. 1998) definition of D (c.f. PATH Preliminary Decision Analysis Report on Snake River Spring/Summer Chinook; Figure 4.2-1 caption) involves terms for “direct survival” of non-transported (in-river) juvenile fish (Vn) and “direct survival” of transported juvenile fish (Vt). This requires estimation of the number of fish in each group (transported or non-transported) that were alive in the river below Bonneville Dam. The counted number of adult returns to Lower Granite Dam in each group is divided by the estimated number of juveniles below Bonneville to estimate post-Bonneville survival. The estimate of D is calculated as the ratio of post-Bonneville survival for the transported group to post-Bonneville survival for the non-transported group.

For a given dam, the expected return rates (SARs) for transported and non-transported fish are each composed of two components: the expected survival probability from the dam to below Bonneville Dam, and the expected survival probability from below Bonneville Dam to adult return. The SARs can be described by the equations

$$SAR_T = S_T \cdot \lambda_T$$

and

$$SAR_I = S_I \cdot \lambda_I$$

where the subscripts *T* and *I* refer to transported and non-transported (in-river fish), respectively; *S* is the downstream survival component, and l is the post-Bonneville Dam component. The ratio of the SARs is the familiar *T:I* ratio:

$$T{:}I = \frac{SAR_T}{SAR_I} = \frac{S_T}{S_I} \cdot \frac{\lambda_T}{\lambda_I} = \frac{S_T}{S_I} \cdot D$$

This equation decomposes the *T:I* ratio into downstream and post-Bonneville Dam components, and introduces the parameter *D*, which is the ratio of post-Bonneville Dam survival for transported fish to that for non-transported fish. If transported fish and non-transported fish have the same survival probability from the transport release site to return as adults, then *D*=1.0. If transported fish incur greater mortality after release from the barge, then *D*<1.0.

Transportation benefits fish stocks from a particular location only if the expected SAR for transported fish exceeds that for non-transported fish; that is, if the *T:I* ratio is expected to exceed 1.0. Because S_T (survival in the barge from the collection dam to below Bonneville Dam) is near 1.0, the decision reduces to comparing survival to below Bonneville for fish left in the river versus differential post-Bonneville Dam survival. In terms of the equations, transportation benefits fish only if $D > S_I$.

One consequence of this relationship is that if *D* is the same for each transportation site, then the benefit of transportation is greater for collection sites farther upstream. This is because S_I increases for sites farther downstream. In other words, fish transported from Lower Granite Dam avoid the higher direct mortality incurred by fish prior to their collection and transportation from McNary Dam.

The definition of Vt implies that the value depends on the collection site, thus we apply a separate value for each collection site. We do not make a survival estimate from above Lower Granite Dam to the Lower Granite Dam tailrace, as both non-transported and transported juveniles transit the same area in common, and thus, any value cancels out of calculations without any effect on estimated D.

The estimated number of non-transported control group fish alive below Bonneville Dam is derived by multiplying the annual estimate of the number of "control" fish arriving at Lower Granite Dam by the estimated annual average survival between Lower Granite and Bonneville Dam tailrace (the "Vn" described above). With the PATH definition, it is impossible to calculate date-specific differential survival between transported fish and the "true" control group within a single migration season. While we can estimate the number of juveniles in the "never-detected" category that passed Lower Granite Dam on any particular day, we have no way of knowing what day a returning adult in that category passed Lower Granite Dam as a juvenile. Thus, we can't calculate the SAR for the never-detected group for a specific date.

Non-PATH derived D

We also evaluated data to determine how differential post-Bonneville survival between transported and non-transported groups might change throughout a single migration season. As identified above, we used fish marked at Lower Granite Dam and compared transported fish to those released into the tailrace that subsequently had the same detection history as the untagged population of fish. We used 6-day running average SARs (LGR juveniles and LGR adults, plotted against date at LGR) to evaluate temporal changes in SARs of the transported and non-transported fish. We used the same methods to determine temporal D values as we did to determine average D over the season.

Factors That Influence SAR Estimates

For most adult return analyses, we compare SARs derived from PIT-tagged fish. These analyses provide the evidence for differences in treatments, for instance, different passage routes or transportation method. Because we can uniquely identify PIT-tagged fish, we also evaluated probabilities of detection for PIT-tagged fish to determine if biases in detection may exist for fish from different treatments (Zabel et al. In review). Additionally, as detailed above, we used methods that did not rely on PIT-tagged fish to estimate annual SARs in recent years for the wild Snake River spring/summer chinook population as a whole. We compared these estimates to those of SARs derived from PIT-tagged fish to check for potential differences and biases.

Most studies using PIT-tagged fish that have evaluated bypass systems and survival through dams have as a basic assumption that the tagged fish have a homogeneous distribution passing dams. Zabel et al.(In review) estimated the relationship between detection probability (at Little Goose, Lower Monumental and McNary Dams) versus length at tagging for spring/summer chinook salmon and steelhead (hatchery and wild) PIT tagged and released at Lower Granite Dam during the years 1998 through 2002. They demonstrated that smaller fish are consistently detected at higher rates than larger ones at all three dams and for all fish groups examined (Figures 2 and 3). Coupled with the results from Zabel and Williams (2002) that larger spring/summer chinook salmon smolts return at higher rates than smaller ones, this may, at least partially, explain why multiple-bypassed fish in early analyses returned at lower rates than undetected ones (Sandford and Smith 2002). Fortunately, for applications of PIT tags in determining juvenile survival through the hydropower system, Zabel et al. (In review) found that although a heterogenous size distribution of fish passed through bypass systems, spill, and turbines, it did not bias survival estimates (Figure 4.)

Delayed Mortality

Delayed mortality is defined as mortality attributable to the hydropower system that is not expressed until after fish leave the hydropower system. To evaluate "delayed mortality", we compared historic SARs for wild Snake River spring/summer chinook salmon to those in recent years. Differences in rates not explainable by differential mortality from transportation ("D") might constitute evidence for delayed mortality. Additionally, Budy et al. (2002)hypothesized a large number of possible mechanisms to explain how the construction of the lower Snake River dams caused delayed mortality. They suggested that migration of juveniles through bypass systems at dams led to delayed mortality. To evaluate this possibility, we used the Sandford and Smith (2002) methodology to develop information for PIT-tagged fish with different juvenile bypass system histories. Based on adult returns, we placed fish into 1 of 5 categories: 1) not detected as juveniles passing downstream through LGR, LGO, LMO, or MCN; 2) detected once at any of these dams; 3) detected twice at some combination of these dams; 4) detected 3 times at some combination of these dams; 5) detected at all four dams. We analyzed wild and hatchery steelhead and wild and hatchery spring-summer chinook salmon PIT-tagged above LGR in the year of their migration. We reported results only in cases where at least 5 adults returned for any one category. We estimated the 95% confidence bounds for the return rates for each category. Our null hypothesis was that the number of juvenile detections (equates to number of bypass systems) had no impact on adult return, against the alternative that increased detections led to decreased (or increased) adult returns. We compared return rates relative to the non-detected group for each category, as we assumed under this hypothesis mechanisms causing delayed mortality would have little to no impact on fish not passing through bypass systems. For purposes of comparison, we set the non-detected return rate to 1.0. If the 95% confidence interval around the estimated relative return rate for fish in a bypass category did not contain 1.0, it indicated a significant difference in return rates.

Selective Mortality

As another way to analyze SAR data, we determined whether fish with certain traits survive at higher rates than the rest of the general population (Zabel and Williams 2002). We examined the traits length at tagging, and release date. In this Tech Memo we expand upon results presented by Zabel and Williams (2002).

The first step in the analysis involved calculating the directional selection coefficient (Endler 1986), which for a trait x, defined as:

$$\delta = \frac{\overline{x}_R - \overline{x}_T}{\sqrt{\mathrm{var}_T}}$$

where $\overline{X}$ is the mean value of the trait in the entire tagged population (T) and in returning adults (R). Note that the returning adults represent a sub-population of the entire tagged population, and we are referring to their traits at the time of tagging. For instance, for the trait "length" a positive value of d means that larger fish returned at a higher rate than smaller ones. We performed a Monte Carlo test (see Zabel and Williams 2002 for details) to determine whether the selection coefficient was significantly different from zero.

ESUs Other than Snake River Spring-summer Chinook Salmon

For most of the listed ESUs other than Snake River spring-summer chinook salmon, recent data do not exist since "White Papers" were written in 1999 to conduct analyses on empirically derived SARs to determine recent impacts of the FCRPS on the stocks. Where possible, we compared trends in adult returns from other ESUs to those for Snake River spring-summer chinook salmon. We used this qualitative review to speculate on FCRPS impacts to other stocks. In some cases, we could reach no conclusions.

RESULTS

Trends in Populations

Estimated SARs (catch + escapement) of Snake River wild spring-summer chinook salmon from the 1999 and 2000 outmigrations increased to levels only previously observed prior to construction of the final mainstem dams in the FCRPS (Figure 5). The median SAR of 3.94 (range 2.17 to 4.51) from the 1998 to 2000 outmigrations was 5.9 times higher than the median SAR of 0.67 (range 0.20 to 1.31) from the 1988 to 1997 outmigrations. From the low-flow 2001 outmigration, the SAR presently stands at ca. 1.5%, with 3-ocean fish yet to return in the spring-summer of 2004. This return rate already exceeds total SARs for all Snake River wild spring-summer chinook outmigrations between 1976 and 1997. Absolute increases in total adult returns of other upper river populations over the past 3 years increased a comparable amount (Figure 6). Median counts of wild upper river summer steelhead at Bonneville Dam increased from 33 k (range 24 to 58 k) to 143 k (range 112 to 149 k). Median counts of Snake River wild steelhead at Ice Harbor Dam increased from 10 k (range 8 to 21 k) to 46 k (range 46 to 51 k). Median counts of Upper Columbia River spring chinook salmon (hatchery and wild combined) at Priest Rapids Dam increased from 10 k (range 1 to 28 k) to 34 k (range 17 to 50 k). Median counts of Snake River fall chinook salmon (natural origin fish) at Lower Granite Dam increased from ca. 475 fish (range 78 to ca. 900) to 2,116 (range 1,148 to 5,163).

Travel-time Estimates for Juvenile Fish

Snake River Yearling Migrants

With the exception of the low flow year of 2001, the annual median travel time (in days) for all Snake River spring-summer chinook salmon and steelhead passing between Lower Granite and Bonneville Dams from 1 April to 31 May each year varied by only a few days, as follows:

Year	Chinook	Steelhead
1995	18.4	20.2
1996	16.2	15.3
1997	14.1	12.2
1998	19.0	14.4
1999	16.1	15.4
2000	16.4	13.6
2001	31.0	29.8
2002	16.9	18.4
2003	14.4	15.4

Based on earlier data derived from Raymond (1979), these times were approximately 40-50% longer than when only 4 dams existed in the mainstem Snake and Columbia Rivers.

Juvenile Survival Estimates for Downstream Migrants

Snake River Basin Hatcheries to Lower Granite Dam Tailrace

Spring-summer chinook salmon

Mean estimated survival from Snake River Basin hatcheries to the tailrace of Lower Granite Dam (average for hatcheries combined) has ranged from a low of 0.494 in 1997 to 0.697 in 2000 with an increase in survival since 1998 compared to earlier years (Table 2). A strong inverse relationship exists between survival and migration distance ($r^2 = 0.941$, $p<0.001$) (Figure 7), with average survival the highest (0.765) from Dworshak National Fish Hatchery, 116 km from Lower Granite Dam, and the lowest (0.403) from Sawtooth National Fish Hatchery, 747 km from Lower Granite Dam.

Table 2. Estimated survival for yearling chinook salmon from Snake River Basin hatcheries to the tailrace of Lower Granite Dam, 1993-2003. Distance from each hatchery to Lower Granite Dam in parentheses in header. Standard errors in parentheses following each survival estimate.

Year	Dworshak (116)	Kooskia (176)	Imnaha River weir (209)	Rapid River (283)	McCall (457)	Pahsimeroi (630)	Sawtooth (747)	Mean
1993	0.647 (0.028)	0.689 (0.047)	0.660 (0.025)	0.670 (0.017)	0.498 (0.017)	0.456 (0.032)	0.255 (0.023)	0.554 (0.060)
1994	0.778 (0.020)	0.752 (0.053)	0.685 (0.021)	0.526 (0.024)	0.554 (0.022)	0.324 (0.028)	0.209 (0.014)	0.547 (0.081)
1995	0.838 (0.034)	0.786 (0.024)	0.617 (0.015)	0.726 (0.017)	0.522 (0.011)	0.316 (0.033)	0.230 (0.015)	0.576 (0.088)
1996	0.776 (0.017)	0.744 (0.010)	0.567 (0.014)	0.588 (0.007)	0.531 (0.007)	—	0.121 (0.017)	0.555 (0.096)
1997	0.576 (0.017)	0.449 (0.034)	0.616 (0.017)	0.382 (0.008)	0.424 (0.008)	0.500 (0.008)	0.508 (0.037)	0.494 (0.031)
1998	0.836 (0.006)	0.652 (0.024)	0.682 (0.006)	0.660 (0.004)	0.585 (0.004)	0.428 (0.021)	0.601 (0.033)	0.635 (0.046)
1999	0.834 (0.011)	0.653 (0.031)	0.668 (0.009)	0.746 (0.006)	0.649 (0.008)	0.584 (0.035)	0.452 (0.019)	0.655 (0.045)
2000	0.841 (0.009)	0.734 (0.027)	0.688 (0.011)	0.748 (0.007)	0.689 (0.010)	0.631 (0.062)	0.546 (0.030)	0.697 (0.035)
2001	0.747 (0.002)	0.577 (0.019)	0.747 (0.003)	0.689 (0.002)	0.666 (0.002)	0.621 (0.016)	0.524 (0.023)	0.653 (0.032)
2002	0.819 (0.011)	0.787 (0.036)	0.667 (0.012)	0.755 (0.003)	0.592 (0.006)	0.678 (0.053)	0.387 (0.025)	0.669 (0.055)
2003	0.720 (0.008)	0.560 (0.043)	0.715 (0.012)	0.691 (0.007)	0.573 (0.006)	0.721 (0.230)	0.595 (0.149)	0.654 (0.028)
Mean	0.765 (0.026)	0.671 (0.032)	0.665 (0.015)	0.653 (0.034)	0.571 (0.024)	0.526 (0.045)	0.403 (0.052)	

Salmon and Snake River Traps to Lower Granite Dam Tailrace

Spring-summer chinook salmon

Estimated survival to the tailrace of Lower Granite Dam for yearling chinook salmon PIT-tagged at the Salmon River trap, 223 km above Lower Granite Dam, averaged 0.777 for hatchery fish and 0..862 for wild fish from 1993 - 2003 (Table 3).

Table 3. Estimated survival from the Salmon River (Whitebird) trap to Lower Granite Dam tailrace (233 km), 1993-2003. Standard errors in parentheses. Simple arithmetic means across all years are given.

Year	Hatchery chinook	Wild chinook	Hatchery steelhead	Wild steelhead
1993	0.782 (0.019)	0.832 (0.014)	0.875 (0.011)	0.832 (0.019)
1994	0.761 (0.024)	0.817 (0.017)	NA	NA
1995	0.802 (0.012)	0.863 (0.011)	0.882 (0.013)	0.892 (0.025)
1996	0.735 (0.026)	0.822 (0.029)	0.851 (0.022)	0.956 (0.060)
1997	NA	NA	0.872 (0.017)	0.876 (0.062)
1998	0.740 (0.012)	0.926 (0.016)	0.879 (0.016)	0.892 (0.070)
1999	0.800 (0.013)	0.909 (0.012)	0.825 (0.014)	0.816 (0.039)
2000	0.806 (0.015)	0.920 (0.021)	0.870 (0.019)	0.815 (0.041)
2001	0.819 (0.007)	0.878 (0.009)	0.786 (0.009)	0.878 (0.019)
2002	0.792 (0.016)	0.844 (0.016)	0.814 (0.041)	0.780 (0.050)
2003	0.728 (0.016)	0.807 (0.011)	0.885 (0.028)	0.952 (0.092)
Mean	0.777 (0.010)	0.862 (0.014)	0.854 (0.011)	0.869 (0.018)

Estimated survival from the Snake River trap, at the head of Lower Granite Reservoir 52 km above Lower Granite Dam, to the tailrace of Lower Granite Dam averaged 0.929 for hatchery yearling chinook salmon and 0.935 for wild yearling chinook salmon from 1993 - 2003 (Table 4).

Table 4. Estimated survival from the Snake River trap (near head of Lower Granite Reservoir) to Lower Granite Dam tailrace (52 km), 1995-2003. Standard errors in parentheses. Simple arithmetic means across all years are given.

Year	Hatchery chinook	Wild chinook	Hatchery steelhead	Wild steelhead
1993	0.823 (0.016)	0.847 (0.024)	0.917 (0.008)	0.898 (0.009)
1994	0.951 (0.029)	0.913 (0.036)	NA	NA
1995	0.886 (0.013)	0.944 (0.015)	0.936 (0.011)	0.955 (0.013)
1996	0.974 (0.032)	0.984 (0.039)	0.941 (0.020)	0.973 (0.022)
1997	NA	NA	0.963 (0.016)	0.968 (0.051)
1998	0.928 (0.013)	0.915 (0.019)	0.926 (0.010)	0.919 (0.017)
1999	0.930 (0.013)	0.950 (0.011)	0.908 (0.012)	0.910 (0.024)
2000	0.911 (0.018)	0.951 (0.023)	0.947 (0.014)	0.977 (0.027)
2001	0.956 (0.015)	0.921 (0.058)	0.893 (0.008)	0.958 (0.010)
2002	0.925 (0.027)	0.985 (0.038)	0.893 (0.019)	0.899 (0.023)
2003	1.001 (0.030)	0.943 (0.033)	0.946 (0.018)	0.893 (0.026)
Mean	0.929 (0.016)	0.935 (0.013)	0.927 (0.008)	0.935 (0.011)

Steelhead

Estimated survival for wild steelhead was nearly identical to chinook salmon. Estimated survival to the tailrace of Lower Granite Dam for steelhead PIT-tagged at the Salmon River trap has averaged 0.854 for hatchery fish and 0.869 for wild fish (Table 3). Estimated survival from the Snake River trap to the tailrace of Lower Granite Dam has averaged 0.927 for hatchery steelhead and 0.935 for wild steelhead (Table 4).

Comparison Between Wild and Hatchery Fish

Wild yearling chinook salmon and steelhead have similar to slightly higher survival compared to hatchery reared fish between the Salmon and Snake River traps and the tailrace of Lower Granite Dam (Tables 3 and 4). Hatchery and wild yearling chinook salmon had similar average estimated survival from the tailrace of Lower Granite Dam to the tailrace of McNary Dam, through 4 dams and reservoirs (Table 5). Annually, estimated survival has been similar between hatchery and wild yearling chinook salmon, with neither stock having consistently higher survival. For steelhead, estimated survival through this reach has averaged about 5%

higher for wild fish (0.586) compared to steelhead of hatchery origin (0.533), with wild steelhead survival higher in 4 of the 6 years compared (Table 5).

Table 5. Estimated survival from Lower Granite Dam tailrace to McNary Dam tailrace for hatchery and wild yearling chinook salmon and steelhead, 1998-2003. Standard errors in parentheses. Simple arithmetic means across all years are given.

Year	Hatchery chinook	Wild chinook	Hatchery steelhead	Wild steelhead
1998	0.773 (0.012)	0.771 (0.015)	0.644 (0.015)	0.698 (0.030)
1999	0.791 (0.007)	0.791 (0.014)	0.673 (0.019)	0.746 (0.019)
2000	0.763 (0.026)	0.775 (0.014)	0.574 (0.038)	0.714 (0.028)
2001	0.556 (0.019)	0.541 (0.027)	0.170 (0.013)	0.168 (0.010)
2002	0.759 (0.008)	0.768 (0.026)	0.533 (0.045)	0.593 (0.039)
2003	0.746 (0.019)	0.729 (0.020)	0.606 (0.028)	0.597 (0.022)
Mean	0.731 (0.036)	0.729 (0.039)	0.533 (0.075)	0.586 (0.087)

The similarity in survival between PIT tagged hatchery and wild fish through this reach and from the Snake River trap to the tailrace of Lower Granite Dam, about 50% of the hydropower system, supports the use of hatchery fish as surrogates for wild fish in estimating juvenile downstream migrant survival for these stocks.

Head of Lower Granite Dam Reservoir to Bonneville Dam Tailrace

Yearling chinook salmon

Estimated yearling chinook salmon (hatchery and wild combined) survival through the entire hydropower system, from the Snake River trap at the head of Lower Granite Reservoir to the tailrace of Bonneville Dam, through eight mainstem dams and reservoirs has ranged from 0.267 in the low-flow year of 2001 to 0.551 in 2002 (Table 6).

Steelhead

Estimated steelhead (hatchery and wild combined) survival through the entire hydropower system has ranged from a low of 0.038 in the low-flow conditions of 2001 to 0.462 in 1998. Based on PIT-tag recoveries, avian predation played a significant role in losses (wild and hatchery combined) based on the percent of PIT-tagged smolts detected at Lower Monumental Dam and later detected on McNary pool bird colonies (Table 7).

Table 6. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River yearling chinook salmon and steelhead (hatchery and wild combined), 1997-2003. Standard errors in parentheses. Abbreviations: Trap-Snake River Trap; LGR-Lower Granite Dam; BON-Bonneville Dam.

Year	Trap-LGR	LGR-BON	Trap-BON
		Yearling Chinook Salmon	
1997	NA	NA	NA
1998	0.925 (0.009)	NA	NA
1999	0.940 (0.009)	0.557 (0.046)	0.524 (0.043)
2000	0.929 (0.014)	0.486 (0.093)	0.452 (0.087)
2001	0.954 (0.015)	0.279 (0.016)	0.266 (0.015)
2002	0.953 (0.022)	0.578 (0.060)	0.551 (0.057)
2003	0.993 (0.023)	0.532 (0.023)	0.528 (0.023)
		Steelhead	
1997	0.964 (0.015)	0.474 (0.069)	0.457 (0.067)
1998	0.924 (0.009)	0.500 (0.054)	0.462 (0.050)
1999	0.908 (0.011)	0.440 (0.018)	0.400 (0.016)
2000	0.964 (0.013)	0.393 (0.034)	0.379 (0.032)
2001	0.911 (0.007)	0.042 (0.003)	0.038 (0.003)
2002	0.895 (0.015)	0.262 (0.050)	0.234 (0.045)
2003	0.932 (0.015)	0.309 (0.011)	0.288 (0.011)

Table 7. Percentage of PIT-tagged smolts detected at Lower Monumental Dam subsequently detected on bird colonies in the McNary Dam reservoir.

Year	Yearling chinook salmon	Steelhead
1998	0.49	4.20
1999	0.84	4.51
2000	0.98	3.66
2001	5.59	21.06
2002	1.19	10.09
2003[a]	1.06	3.71

[a] Only the Crescent Island Caspian tern colony sampled

Snake River subyearling chinook salmon

Summer-migrating subyearling fall chinook salmon have a much more complex migration pattern than spring-migrating salmonids, thus, results from PIT-tag studies do not fall into neat, discrete parts. Most data on fall chinook survival come from studies conducted above Lower Granite Dam. Since 1992, Connor et al. (2003a) have beach seined, PIT-tagged, and released fall wild chinook in their rearing areas. Since 1995, NOAA Fisheries has also PIT-tagged subyearling fall chinook at Lyons Ferry Hatchery, trucked them upstream above Lower Granite Dam, and released them at a time and size to match wild subyearling fall chinook salmon in their rearing areas (Smith 2003). As travel time to the Lower Granite Dam dam typically averages one month or more from time of release after tagging, survival estimates to Lower Granite Dam, represent survival during both rearing and migration (Connor et al. 2003a, Connor et al. 2003b, Smith 2003). Subyearling fall chinook salmon rear and develop physiologically as they migrate, and their migration rate increases with migration distance and increased size. Unlike yearling smolts that generally all migrate quickly to Lower Granite Dam, some fall chinook don't for months. Thus, standard techniques used for yearling smolts to measure travel times or survival don't work quite as well. From 1995 to 2000, we released nearly 200,000 PIT-tagged smolts above Lower Granite Dam. Subsequently we detected only about 62,000. Of these nearly 15% were not detected at a Snake River dam until after 1 September of the year, some not until the following spring. For the "active" migrants, those that passed the Snake River dams in June, July, and August in the year of release for the hatchery fish, the median pooled travel time for all years from release to detection at Lower Granite Dam averaged 43.5 days (Smith 2003). Within each migration year, median migration rate between each pair of dams was substantially greater between Lower Monumental and McNary Dams and between McNary and Bonneville Dams than between pairs of dams upstream from Lower Monumental Dam (Figure 8)

The survival of both wild and hatchery fish to Lower Granite Dam has varied widely among years and within years with survival declining as the migration season progresses, flows decrease, and water clarity and temperature increases (Connor et al. 2003a, Smith 2003). Certainly, a need exists for an estimated average survival through the Lower Granite Dam reservoir, but with data collected to date, we cannot partition what portion of the mortality occurred within the hydropower system as measures of survival (and travel time) represent both rearing and migration.

Connor et al.(2003a) divided wild subyearling fall chinook salmon into four equally sized cohorts each year (1998-2000), and estimated 57-88% survival to Lower Granite Dam tailrace for the earliest migrating cohort PIT-tagged in early to mid-May to 36% for fish tagged in mid-June. For hatchery subyearling chinook salmon, estimated survival was 35-55% for early June releases, 16-49% for mid-June releases, and 2-24% for the last releases in early July for fish released near Asotin, Washington, at Billy Creek during those years (Figure9) (Smith 2002, 2003).

Estimating survival for subyearling chinook salmon below Lower Granite Dam has also been difficult. Because of lower detection efficiencies (because of lower fish guidance efficiencies for fall chinook), fewer PIT-tagged fish, poor survival to Lower Granite Dam, and fish dispersed over a wide time period, survival for Snake River fall chinook has only been estimated as far as the tailrace of Lower Monumental Dam, and only for fish of hatchery origin (Smith 2002, 2003). Survival between the tailrace of Lower Granite Dam and the tailrace of Lower Monumental Dam has been highly variable, with a general decline in mid to late-August, and much lower overall than for spring migrating yearling chinook salmon (Figure 10).

We have no survival estimates for juvenile fish that migrate in September and October, nor for undetected fish. Based on adult returns, however, the two groups accounted for 14 and 36% of the total adult return from PIT-tagged fish.

Upper Columbia River yearling migrants

Fewer years of PIT-tag data exist for fish stocks from the Upper Columbia River basin compared to those in the Snake River Basin. Nonetheless, the data indicate that juveniles migrating from the Snake And Columbia River basins under normal flow conditions have similar survival (Tables 5 and 6 compared to Tables 8, 9, and 10). This was not the case in the 2001 low-flow year. Fish from the Upper Columbia River had higher estimated survival to the McNary Dam tailrace (hatchery releases) and sometimes Bonneville Dam tailrace (dam releases) than did fish from the Snake River. A spill program existed at upper Columbia River dams in 2001, but not at Snake River dams, thus possibly explaining some of the difference in survival. For fish released at dams, a stock effect may also have played a part. Yearling summer-fall chinook released at Upper Columbia River dams also had higher survival from McNary Dam to Bonneville Dam, whereas

Table 8. Summary of survival and smolt-to-adult returns for upper Columbia River chinook. Hatchery and wild fish released upstream of Rock Island Dam are designated "Above RIS", hatchery fish released downstream of Rock Island Dam are designated "Below RIS", and wild fish released above the confluence of the Columbia and Yakima Rivers are designated "Above Yakima". Summer chinook released from Wells Hatchery are a separate category. Abbreviations: REL-release site, MCN-McNary Dam, JDA-John Day Dam, BON-Bonneville Dam, RIS-Rock Island Dam.

				REL-MCN		MCN-JDA		MCN-BON	
Year	Release Site	N	SAR	S	se	S	se	S	se
Hatchery spring chinook									
1999	Above RIS	14,894	0.0020	0.570[b]	0.015	0.890[b]	0.018		
2000	Above RIS	14,877	0.0095	0.543[b]	0.051	0.892[b]	0.064		
2001	Above RIS	15,014	0.0007	0.461	0.036	0.812	0.051	0.640	0.219
2002	Above RIS	404,138	0.0001	0.522	0.017	0.856	0.012	0.742	0.068
2003	Above RIS	355,321	0.0000	0.559	0.025	0.892	0.006	0.710	0.040
Hatchery summer chinook									
1999	Wells Hatchery	5,998	0.0007	0.390[b]	0.050	1.258[b]	0.520	1.252	0.675
2000	Wells Hatchery	5,997	0.0005	0.208[b]	0.020	0.582	0.081	0.404	0.060
	Above RIS	45,981	0.0449	0.962	0.011	0.738	0.012	0.513	0.028
2001	Wells Hatchery	6,000	0.0000	0.214[b]	0.020	0.407[b]	0.100		
	Above RIS	90,118	0.0054	0.723	0.026	0.863	0.018	0.679	0.060
	Below RIS	113,333	0.0039	0.817	0.031	0.922	0.009	0.727	0.047
2002	Wells Hatchery	5,992	0.0002	0.450[b]	0.030	0.792[b]	0.160	0.952	0.260
	Above RIS	90,125	0.0001	0.771	0.024	0.866	0.013	1.041	0.189
2003	Wells Hatchery	5,996	0.0000	0.449	0.025	1.158	0.456		
	Above RIS	103,907	0.0000	0.787	0.034	0.856	0.035	0.724	0.036
	Below RIS	117,149	0.0000	0.767	0.024	0.942	0.022	0.628	0.120
Hatchery fall chinook									
1999	Below RIS	6,778	0.0012	0.800[b]	0.037	0.720[b]	0.017		
2000	Below RIS	6,091	0.0031	0.624[b]	0.068	0.483[b]	0.069		
2001	Below RIS	35,762	0.0004	0.667[b]	0.050	0.683[b]	0.062		
2002	Below RIS	66,554	0.0008	0.716[b]	0.019	0.778[b]	0.030	0.613	0.093
2003	Below RIS	81,253	0.0000	0.558	0.034	0.820	0.042		
Wild spring chinook									
2003	Above RIS	6,402	0.0000	0.324	0.021	1.072	0.033	0.793	0.062
Wild fall chinook									
1999	Above	5,042	0.0014	0.398	0.024	0.833	0.119		

	Yakima						
	Above	10,967	0.0067	0.432	0.035		
2000	Yakima						
	Above	9,481	0.0005	0.366	0.025	0.563	0.029
2001	Yakima						
	Above	414	0.0000	0.402	0.058	0.696	0.290
2002	Yakima						
	Above	2,975	0.0000	0.315	0.020	0.600	0.122
2003	Yakima						

[a]Includes data from Bickford et al. 2001
[b]Includes data from Columbia Basin Research (www.cbr.washington.edu/pitSurv/)

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Table 9. Summary of survival and smolt-to-adult returns for Yakima River chinook. Fish released at or upstream of Roza Dam are designated "Upper Yakima" and fish released downstream of Roza Dam are designated "Lower Yakima". Abbreviations: REL-release site, MCN-McNary Dam, JDA-John Day Dam, BON-Bonneville Dam.

				REL-MCN		MCN-JDA		MCN-BON	
Year	Release Site	N	SAR	S	se	S	se	S	se
Hatchery spring chinook									
1999	Upper Yakima	39,702	0.0051	0.472	0.023	0.929	0.024		
2000	Upper Yakima	40,417	0.0155[a]	0.350[b]	0.024	0.683	0.041		
	Lower Yakima	7,929	0.0193	0.749	0.025	0.683	0.041		
2001	Upper Yakima	41,234	0.0007[a]	0.228[b]	0.014	0.757	0.040		
	Lower Yakima	895	0.0000	0.496	0.022	0.812	0.105		
2002	Upper Yakima	40,701	0.0012	0.311[b]	0.024	0.938	0.036	1.079	0.143
	Lower Yakima	1,261	0.0000	0.520	0.030	0.938	0.036	0.334	0.175
2003	Upper Yakima	41,671	0.0000	0.253	0.030	1.041	0.071	0.951	0.159
	Lower Yakima	4,308	0.0000	0.510	0.022	0.877	0.079	0.802	0.142
Hatchery fall chinook									
1999	Lower Yakima	7,324	0.0016	0.588	0.108	0.669	0.053		
2000	Lower Yakima	4,051	0.0022	0.645	0.119	0.573	0.137		
2001	Lower Yakima	3,979	0.0005	0.330	0.037	0.696	0.113		
2002	Lower Yakima	4,001	0.0005	0.223	0.011	0.867	0.132	0.627	0.230
2003	Lower Yakima	3,987	0.0000	0.183	0.083	0.783	0.071	0.561	0.051
Wild spring chinook									
1999	Upper Yakima	312	0.0032[a]	0.611[b]		0.866	0.056		
	Lower Yakima	3,040	0.0069	0.774	0.022	0.866	0.056		
2000	Upper Yakima	6,209	0.0322[a]	0.487[b]		0.814	0.055		
	Lower Yakima	5,727	0.0386	0.819	0.036	0.795	0.048		
2001	Upper Yakima	2,179	0.0046[a]	0.149[b]		0.631	0.070		
	Lower Yakima	1,606	0.0031	0.688	0.019	0.658	0.055		
2002	Upper Yakima	8,717	0.0001[a]	0.339[b]		0.870	0.054	0.801	0.373
	Lower Yakima	3,022	0.0007	0.643	0.010	0.870	0.054	0.545	0.218
2003	Upper Yakima	7,803	0.0000	0.274	0.015	0.883	0.113	0.691	0.271
	Lower Yakima	9,333	0.0000	0.637	0.008	0.768	0.045	0.888	0.067
Wild fall chinook									
1999	Lower Yakima	876	0.0023	0.790	0.021	0.720	0.188		
2000	Lower Yakima	1,979	0.0020	0.272	0.025				

[a]Includes data from Bill Bosch, Yakama Indian Nation (pers. comm.)
[b]Includes data from Neely, 2002.

Table 10. Summary of survival and smolt-to-adult returns for upper Columbia and Yakima River steelhead. In the upper Columbia River, hatchery fish released upstream of Rock Island Dam are designated "Above RIS" and wild fish were released at Rock Island Dam. In the Yakima River, fish released downstream of Roza Dam are designated "Lower Yakima". Abbreviations: REL-release site, MCN-McNary Dam, JDA-John Day Dam, BON-Bonneville Dam, RIS-Rock Island Dam.

				REL-MCN		MCN-JDA		MCN-BON	
Year	Release Site	N	SAR	S	se	S	se	S	se
Hatchery summer steelhead									
1999	Above RIS	134,251	0.0039	0.616	0.013	1.016	0.013		
2000	Above RIS	63,227	0.0174	0.607	0.009	0.861[a]	0.059		
2001	Above RIS	4,029	0.0005	0.203	0.029	0.535	0.146	0.178	0.078
2002	Above RIS	3,623	0.0108	0.529	0.107	1.119	0.168	0.856	0.349
2003	Above RIS	391203	0.0000	0.447	0.014	1.027	0.025	0.800	0.042
Wild summer steelhead									
1999	Rock Island Dam	1,156	0.0043	0.635	0.055	1.103	0.148		
2000	Rock Island Dam	1,200	0.0217	0.679	0.102	0.873	0.224		
2001	Rock Island Dam	1,174	0.0009	0.211	0.022	0.304	0.082		
2002	Rock Island Dam	1,200	0.0100	0.623	0.063	0.680	0.125		
Wild spring-summer steelhead (Yakima)									
1999	Lower Yakima	1,241	0.0048	0.798	0.033	0.967	0.099		
2002	Lower Yakima	1,335	0.0180	0.314	0.054	0.924	0.302	0.560	0.585
2003	Lower Yakima	575	0.0000	0.394	0.099	0.860	0.359		

[a]Includes data from Bickford et al., 2001

spring chinook from the Yakima River did not. The Yakima River spring chinook had survival similar to Snake River spring chinook in the lower river.

We estimated the percent of avian predation on Upper Columbia River stocks in 2001 based on numbers of fish released at up river sites (Table 11). They were lower than for groups from the Snake, but do not take into account mortality from release to the head of the McNary Dam reservoir (wide range in values of survival from release to McNary Dam). If mortality averaged 50% to that point, doubling these recovery estimates indicates about avian predators had similar impacts on Upper Columbia River.

Table 11. Estimated percent of PIT-tagged salmonids released in the Upper Columbia River basin subsequently found on the bird colonies in the McNary Dam reservoir.

Year	Yearling Chinook Salmon	Steelhead
1999	0.24	1.92
2000	0.26	2.36
2001	1.38	11.49
2002	0.39	3.81
2003[a]	0.20	1.34

[a] Only the Crescent Island Caspian Tern colony sampled

Upper Columbia River subyearling chinook

Between 1999 and 2002, survival was estimated for subyearling fall chinook salmon in the lower Columbia River between the tailraces of McNary and John Day Dams (Smith 2000b, Smith et al. 2002). Fall chinook salmon (primarily wild fish from the Hanford Reach) PIT-tagged at McNary Dam and released to the tailrace 3 to7 days/week through most of the summer migration had average survival ranging from 58% in 2001 to 78% in 1999 (Table 12).

Table 12. Estimated survival of subyearling fall chinook salmon between the tailrace of McNary and John Day Dams. Standard errors (s.e.) in parentheses.

Year	Survival (s.e.)
1999	0.775 (0.019)
2000	0.774 (0.205)
2001	0.581 (0.016)
2002	0.756 (0.037)

Relationships among flow, temperature, travel time and survival

Yearling migrants

Smith et al. (2002) investigated relationships between survival and travel time and river conditions for migrant yearling chinook salmon and steelhead in the Lower Snake River. Their study included juveniles migrating through the river segment between Lower Granite and McNary Dam tailrace. They concluded that in this limited segment both species showed strong, consistent relationships between flow volume and travel time, and little to no relationship between flow volume and survival.

Data from the 2002 and 2003 migration years continue to show the same result for steelhead. However, the influence of flow on travel time for juvenile spring-summer chinook salmon is not as clear in these data (Figure 11). In each of those 2 years, the early part of the migration season featured relatively long periods of nearly constant flow. In both years, median travel times for spring-summer chinook salmon decreased throughout the period, even without change in flow. This result suggests that physiological characteristics of juvenile fish (possibly degree of smoltification) that progress throughout the season might have more influence on migration rates than flow.

Smith et al. (2002) may have concluded that chinook salmon travel time was related to flow volume simply because flow volume was correlated with date, and hence smoltification, in most of the years of their study. In fact, 1998 was one year in their data set when the same pattern as in 2002 and 2003 was apparent (Figure 11). Smith et al. (2002) noted that the relationship between flow and travel time in 1998 was different from the other years. Data from recent years might point to a cause of that difference.

Data for steelhead from 2002 and 2003 do not show the same pattern (Figure 12). Flow volume (hence water velocity) apparently continues to heavily influence steelhead travel time.

Snake River Subyearling Chinook Salmon

In the Snake River, the migration rate of subyearling fall chinook salmon during their early rearing phase is not much influenced by flow, but as they grow, develop physiologically, and move farther offshore, their migration rate is related to flow (Connor et al. 2003b, Smith 2003). Significant correlations between survival from release above Lower Granite Dam to the tailrace of Lower Granite Dam were found for flow and temperature for wild fish (Connor et al. 2003a) and flow, temperature, and turbidity for hatchery fish (Smith 2003). Because the environmental variables were highly correlated among themselves, determining the relative importance of individual factors was not possible, but all have plausible biological effects on survival. Anderson (2003) argues that increasing temperature most likely leads toward decreased survival.

Upper Columbia subyearling chinook salmon

In the McNary Dam tailrace to John Day Dam tailrace reach, the same relationship among survival, flow, temperature, and turbidity exists as it does for Snake River fall chinook salmon, but with only four data points, is not significant (Figure 13).

Transportation

Based on Sandford and Smith (2002) methodologies applied to fish PIT-tagged above Lower Granite Dam from 1993 through 2003, we estimated that the combined annual percentage of the non-tagged yearling fish in the population transported from Lower Granite, Little Goose, Lower Monumental, and McNary Dams ranged from approximately 62% to nearly 100%, as follows:

Year	Wild chinook	Hatchery chinook	Wild steelhead	Hatchery steelhead
1993	88.5	88.1	93.2	94.7
1994	87.7	84.0	91.3	82.2
1995	86.4	79.6	91.8	94.3
1996	71.0	68.7	79.8	82.9
1997	71.1	71.5	87.5	84.5
1998	82.5	81.4	88.2	87.3
1999	85.9	77.3	87.6	88.5
2000	70.4	61.9	83.9	81.5
2001	99.0	97.3	99.3	96.7
2002	72.1	64.2	75.2	70.4
2003	70.4	61.5	72.9	68.4

Thus, clearly the ultimate effect of the FCRPS on yearling fish from the Snake River basin depends to a high degree on the fate of fish transported from it.

Annual SARs for Spring Migrant Fish

Estimated annual SARs for PIT-tagged chinook salmon marked above Lower Granite Dam during outmigration years 1993 to 2000 ranged from 0.05% for non-transported hatchery chinook salmon to 3.08% for transported wild chinook salmon (Table 13). Estimated annual SARs for PIT-tagged steelhead marked above Lower Granite Dam during outmigration years 1993 to 2000 ranged from 0.10% for non-transported hatchery steelhead to 6.45% for transported wild steelhead (Table 14). The default setting for PIT-tagged fish detected at dams where transportation occurs shunts PIT-tagged fish to bypass pipes for return to the river. As these systems are not 100% effective, small numbers of PIT-tagged fish get transported. To transport greater numbers of PIT-tagged fish requires programming into the system, in advance, PIT-tag codes of fish needed for transportation. As a result of these conventions, with the exception of fish marked for the CSS, only incidental numbers of fish PIT-tagged above Lower Granite Dam get transported. These small numbers lead to large confidence bounds about SARs. When the 95% confidence bounds between two different groups did not overlap, it indicated a significant difference in SARs between the two groups. Confidence bounds overlapped for all comparison groups of wild spring-summer chinook salmon (Table 15) and wild and hatchery steelhead (Table 16). For hatchery spring-summer chinook salmon, the annual SAR for fish transported from Lower Granite Dam was significantly higher than for non-transported (non-detected category) fish from migration years 1997 - 2000.

Table13. Annual SARs (with total adult returns) for spring-summer chinook salmon PIT-tagged above Lower Granite Dam and transported between 1993 and 2000, compared to annual SARs of non-detected fish (fish that represent the migration history for the non-tagged population.) Abbreviations. LGR = Lower Granite Dam, LGO = Little Goose Dam, LMO = Lower Monumental Dam, MCN = McNary Dam

Year	Rearing type	Transported from (first time det.): LGR	LGS	LMN	MCN	Non-detected
1993	Wild	0.10 (2)	-	-	-	
	Hatchery	0.09 (4)	-	-	-	0.06 (2)
1994	Wild	0.74 (8)	0.93 (4)	0.18 (1)	-	0.05 (1)
	Hatchery	0.11 (2)	0.12 (1)	0.11 (1)	0.02 (2)	0.09 (7)
1995	Wild	0.39 (7)	0.29 (1)	-	-NA-	0.47 (9)
	Hatchery	0.59 (14)	0.80 (5)	0.37 (1)	-NA-	0.45 (27)
1996	Wild	0.35 (1)	1.10 (1)	-	-	0.20 (4)
	Hatchery	0.30 (6)	-	-	-	0.17 (29)
1997	Wild	0.99 (2)	6.45 (2)	-	-NA-	1.63 (14)
	Hatchery	0.89 (226)	0.69 (5)	0.66 (22)	-NA-	0.67 (162)
1998	Wild	1.30 (11)	0.89 (3)	0.96 (1)	-NA-	1.43 (31)
	Hatchery	1.74 (812)	0.84 (66)	0.57 (7)	-NA-	1.26 (260)
1999	Wild	2.59 (32)	2.15 (9)	1.75 (7)	-NA-	2.08 (73)
	Hatchery	2.75 (697)	2.91 (481)	1.24 (25)	-NA-	1.83 (567)
2000	Wild	1.07 (4)	1.94 (6)	1.00 (2)	-NA-	2.03 (116)
	Hatchery	3.08 (1029)	2.18 (310)	1.76 (86)	-NA-	1.66 (753)

Table 14. Annual SARs (with total adult returns) for steelhead PIT-tagged above Lower Granite Dam and transported between 1993 and 2000, compared to annual SARs of non-detected fish (fish that represent the migration history for the non-tagged population.) Abbreviations. LGR = Lower Granite Dam, LGO = Little Goose Dam, LMO = Lower Monumental Dam, MCN = McNary Dam

		Rearing	Transported from (first time det.):				Non-
Year	Species	type	LGR	LGS	LMN	MCN	detected
1993	Steelhead	Wild	0.24 (2)	-	-	1.85 (1)	-
		Hatchery	0.05 (1)	0.59 (1)	0.59 (2)	-	0.35 (2)
1994	Steelhead	Wild	1.70 (6)	0.46 (1)	0.52 (1)	-	0.93 (6)
		Hatchery	1.08 (21)	-	0.41 (2)	0.07 (1)	0.10 (7)
1995	Steelhead	Wild	-	-	4.17 (1)	-NA-	-
		Hatchery	0.70 (14)	1.60 (5)	-	-NA-	0.90 (11)
1996	Steelhead	Wild	0.99 (1)	-	-	-NA-	0.35 (2)
		Hatchery	0.36 (4)	-	-	-NA-	0.36 (14)
1997	Steelhead	Wild	1.32 (3)	-	-	-NA-	0.22 (1)
		Hatchery	0.60 (10)	-	-	-NA-	0.19 (8)
1998	Steelhead	Wild	0.33 (1)	-	-	-NA-	1.20 (9)
		Hatchery	0.63 (5)	0.24 (1)	0.52 (1)	-NA-	0.93 (24)
1999	Steelhead	Wild	2.49 (6)	4.21 (4)	2.53 (2)	-NA-	2.68 (25)
		Hatchery	0.95 (8)	1.20 (4)	-	-NA-	1.43 (37)
2000	Steelhead	Wild	2.82 (7)	3.08 (4)	2.11 (3)	-NA-	1.78 (36)
		Hatchery	3.04 (14)	0.98 (1)	0.61 (1)	-NA-	0.97 (39)

Table 15. Confidence intervals (95%) around annual SARs (see Table 13) for chinook salmon PIT-tagged above Lower Granite Dam and transported between 1993 and 2000, compared to intervals around annual SARs of non-detected fish (fish that represent the migration history for the non-tagged population.) Abbreviations. LGR = Lower Granite Dam, LGO = Little Goose Dam, LMO = Lower Monumental Dam, MCN = McNary Dam

	Rearing	Transported from (first time det.):				Non-
Year	type	LGR	LGS	LMN	MCN	detected
1993	Wild	0.00 - 0.19	0.00 - 1.01	-	-	-
	Hatchery	0.02 - 0.17	-	-	-	0.00 - 0.17
1994	Wild	0.36 - 1.12	0.19 - 1.58	0.00 - 0.61	-	0.05 - 0.43
	Hatchery	0.00 - 0.27	0.00 - 0.34	0.00 - 0.23	0.00 - 0.03	0.04 - 0.18
1995	Wild	0.22 - 0.62	0.00 - 0.61	-	-NA-	0.20 - 0.58
	Hatchery	0.30 - 0.83	0.33 - 1.38	0.00 - 0.86	-NA-	0.30 - 0.59
1996	Wild	0.00 - 1.43	0.00 - 3.72	-	-NA-	0.00 - 0.46
	Hatchery	0.20 - 0.44	-	-	-NA-	0.12 - 0.21
1997	Wild	0.00 - 2.22	0.00 - 24.2	-	-NA-	0.81 - 2.64
	Hatchery	0.80 - 0.96	0.31 - 1.12	0.00 - 1.35	-NA-	0.60 - 0.74
1998	Wild	0.72 - 2.31	0.28 - 1.58	0.00 - 3.13	-NA-	1.08 - 1.75
	Hatchery	1.66 - 1.81	0.70 - 0.97	0.32 - 0.81	-NA-	1.16 - 1.36
1999	Wild	1.66 - 3.27	0.71 - 3.38	0.93 - 2.80	-NA-	1.73 - 2.36
	Hatchery	2.56 - 2.95	2.62 - 3.09	0.85 - 1.66	-NA-	1.62 - 1.92
2000	Wild	0.25 - 1.91	0.81 - 3.41	0.00 - 1.81	-NA-	1.80 - 2.48
	Hatchery	2.92 - 3.25	1.86 - 2.42	1.31 - 2.31	-NA-	1.40 - 1.71

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Table 16. Confidence intervals (95%) around annual SARs (see Table 14) for steelhead PIT-tagged above Lower Granite Dam and transported between 1993 and 2000, compared to intervals around annual SARs of non-detected fish (fish that represent the migration history for the non-tagged population.) Abbreviations. LGR = Lower Granite Dam, LGO = Little Goose Dam, LMO = Lower Monumental Dam, MCN = McNary Dam

Year	Rearing type	Transported from (first time det.): LGR	LGS	LMN	MCN	Non-detected
1993	Wild	0.00 - 1.67	1.30 - 5.12	0.00 - 2.68	-NA-	0.42 - 1.25
	Hatchery	0.00 - 0.15	0.00 - 1.84	0.00 - 1.72	-	0.00 - 0.99
1994	Wild	0.29 - 2.91	0.00 - 1.69	0.00 - 1.26	-	0.28 - 1.95
	Hatchery	0.68 - 1.52	-	0.00 - 0.89	0.00 - 0.14	0.04 - 0.15
1995	Wild	-	-	0.00 - 11.7	-NA-	0.00 - 1.22
	Hatchery	0.39 - 1.25	0.62 - 3.15	-	-NA-	0.50 - 1.23
1996	Wild	0.00 - 3.96	-	-	-NA-	0.00 - 1.04
	Hatchery	0.17 - 0.57	-	-	-NA-	0.17 - 0.53
1997	Wild	0.00 - 2.59	-	-	-NA-	0.00 - 0.55
	Hatchery	0.23 - 1.08	-	-	-NA-	0.07 - 0.28
1998	Wild	0.00 - 1.01	-	-	-NA-	0.56 - 1.94
	Hatchery	0.14 - 1.25	0.00 - 0.70	0.00 - 1.64	-NA-	0.65 - 1.22
1999	Wild	0.81 - 4.48	1.07 - 9.01	0.00 - 8.11	-NA-	1.06 - 2.20
	Hatchery	0.49 - 1.64	0.59 - 2.00	-	-NA-	1.08 - 1.86
2000	Wild	0.46 - 5.88	0.79 - 4.61	0.00 - 4.93	-NA-	1.30 - 2.31
	Hatchery	1.54 - 4.61	0.00 - 2.76	0.00 - 2.59	-NA-	0.60 - 1.34

Annual SARs for PIT-tagged juvenile spring-summer chinook salmon marked at Lower Granite Dam during outmigration years 1995 to 2000 ranged from a low of 0.06% for non-transported fish to a high of 2.10% for transported fish (Table 17). Annual SARs for PIT-tagged juvenile steelhead marked at Lower Granite Dam during outmigration years 1998 to 2000 ranged from a low of 0.24% for non-transported to 4.43% for transported fish (Table 18). The fish included in these results were first-time detections at the respective dam. For fish marked at Lower Granite Dam, first time detection was defined as after release from Lower Granite Dam (non-detected fish represented the route of passage of the non-tagged population downstream of Lower Granite Dam). Annual adult returns for wild spring-summer chinook salmon collected and marked at Lower Granite Dam were high enough that sufficiently narrow confidence bounds existed to indicate significantly higher annual SARs for transported fish in 1995 and 1999, but not in 1996, 1998, and 2000 (Table 19). The annual SARs of transported wild and hatchery steelhead were significantly higher for transported fish than non-transported fish from both the 1999 and 2000 outmigration (Table 20). Too few fish returned from marking in 1998 to determine differences in return rates.

Table 17. Annual SARs (with total adult returns) for spring-summer chinook salmon PIT-tagged at Lower Granite Dam for transportation studies between 1995 and 2000, compared to annual SARs of non-detected fish (fish that represent the migration history for the non-tagged population).

Year	Rearing type	Transported from: LGR	LGS	LMN	MCN	Non-detected
1995	Wild	0.38 (92)	0.24 (8)	0.28 (4)	-	0.23 (26)
	Hatchery	0.54 (450)	0.37 (17)	0.30 (5)	-	0.32 (123)
1996	Wild	0.11 (9)	-	-	-	0.06 (3)
	Hatchery	0.13 (47)	0.10 (1)	-	-	0.11 (27)
1997			No studies			
1998	Wild	0.60 (34)	-	-	-NA-	0.95 (28)
	Hatchery	0.62 (245)	0.32 (6)	0.19 (2)	-NA-	0.57 (134)
1999	Wild	2.10 (176)	0.70 (1)	2.41 (15)	-NA-	1.35 (26)
	Hatchery	1.97 (833)	2.09 (12)	1.47 (50)	-NA-	1.45 (242)
2000[a]	Wild	-NA-	1.47 (255)	0.66 (7)	-NA-	1.44 (385)
	Hatchery	-NA-	-NA-	-NA-	-NA-	-NA-

[a] Fish were tagged at Lower Granite Dam, released into tailrace and collected and transported from Little Goose Dam.

Table 18. Annual SARs (with total adult returns) for steelhead PIT-tagged at Lower Granite Dam for transportation studies between 1998 and 2000, compared to annual SARs of non-detected fish (fish that represent the migration history for the non-tagged population).

Year	Rearing type	Transported from: LGR	LGS	LMN	MCN	Non-detected
1998	Wild	-	0.35 (1)	0.72 (3)	-NA-	0.37 (7)
	Hatchery	-	0.71 (7)	0.24 (2)	-NA-	0.41 (24)
1999	Wild	1.42 (86)	0.80 (1)	2.27 (9)	-NA-	0.54 (8)
	Hatchery	1.08 (442)	1.43 (15)	0.99 (22)	-NA-	0.79 (82)
2000	Wild	-NA-	3.96 (979)	4.43 (101)	-NA-	1.85 (435)
	Hatchery	-NA-	1.99 (11)	1.73 (11)	-NA-	0.85 (79)

[a] Fish were tagged at Lower Granite Dam, released into tailrace and collected and transported from Little Goose Dam.

Table 19. Confidence intervals (95%) around annual SARs (see Table 17) for spring-summer chinook salmon PIT-tagged at Lower Granite Dam for transportation studies between 1995 and 2000, compared to intervals around annual SARs of non-detected fish (fish that represent the migration history for the non-tagged population).

Year	Rearing type	Transported from: LGR	LGS	LMN	MCN	Non-detected
1995	Wild	0.30 - 0.45	0.17 - 0.59	0.07 - 0.49	-	0.17 - 0.28
	Hatchery	0.51 - 0.57	0.26 - 0.49	0.13 - 0.50	-	0.28 - 0.36
1996	Wild	0.05 - 0.18	-	-	-	0.02 - 0.15
	Hatchery	0.10 - 0.17	0.00 - 0.21	-	-	0.07 - 0.14
1997			No studies			
1998	Wild	0.46 - 0.77	-	-	-NA-	0.61 - 1.28
	Hatchery	0.58 - 0.68	0.16 - 0.55	0.00 - 0.38	-NA-	0.48 - 0.65
1999	Wild	1.83 - 2.42	0.00 - 2.99	1.51 - 4.00	-NA-	0.94 - 1.80
	Hatchery	1.90 - 2.06	1.05 - 3.25	1.29 - 1.71	-NA-	1.32 - 1.60
2000[a]	Wild	-NA-	1.36 - 1.57	0.39 - 0.95	-NA-	1.36 - 1.57
	Hatchery	-NA-	-NA-	-NA-	-NA-	-NA-

[a] Fish were tagged at Lower Granite Dam, released into tailrace and collected and transported from Little Goose Dam.

Table 20. Confidence intervals (95%) around annual SARs (see Table 18) for steelhead PIT-tagged at Lower Granite Dam for transportation studies between 1998 and 2000, compared to intervals around annual SARs of non-detected fish (fish that represent the migration history for the non-tagged population).

Year	Rearing type	Transported from: LGR	LGS	LMN	MCN	Non-detected
1998	Wild	-NA-	0.00 - 1.05	0.00 - 1.77	-NA-	0.16 - 0.61
	Hatchery	-NA-	0.10 - 1.36	0.00 - 0.69	-NA-	0.27 - 0.56
1999	Wild	1.19 - 1.70	0.00 - 2.39	1.16 - 3.70	-NA-	0.27 - 0.94
	Hatchery	1.02 - 1.14	1.00 - 1.83	0.78 - 1.19	-NA-	0.63 - 0.92
2000[a]	Wild	-NA-	3.80 - 4.12	3.82 - 5.10	-NA-	1.71 - 1.98
	Hatchery	-NA-	1.01 - 3.37	0.87 - 2.85	-NA-	0.71 - 1.06

[a] Fish were tagged at Lower Granite Dam, released into tailrace and collected and transported from Little Goose Dam.

Annual Estimates of Differential Post-Bonneville Dam Survival (D): Transport Location-Specific and Overall

Ultimately, management decisions must consider temporal variation within seasons in SARs for transported and non-transported fish. Other sections in this document include extensive discussion of temporal estimates of SARs and, by extension, temporal variation in for T/I ratios and differential post-Bonneville Dam survival. Here we summarize data on annual estimates of D. Annual estimates provide a general description of differences in return rates between transported and non-transported groups, and differences between transport locations. Again, we must repeat our caution that annual estimates of D require careful interpretation and have value only when considered in conjunction with in-season variation. Annual estimates of D are potentially misleading when there are large in-season variations.

Large adult returns in recent years have generally improved our ability to estimate differential post-Bonneville Dam survival separately for each transportation dam, and greatly increased the precision on the overall estimate. In all four cases of hatchery and wild Snake River spring-summer chinook salmon and steelhead, the greatest number of returning PIT-tagged adults have occurred in 1999 and 2000 (Tables 21 through 24).

No apparent consistent results exist. To summarize results, we offer the following, sometimes tentative, observations and conclusions:

(1) For all four species and rearing-type combinations, the geometric mean annual estimated D from migration years 1994 through 2000 ranges between 0.55 and 0.63. That is, averaged over years and throughout migration seasons, survival for transported fish from below Bonneville Dam as a juvenile to return as an adult has averaged less than two-thirds that of the non-transported fish that arrived below Bonneville Dam.

(2) Wild and hatchery spring-chinook salmon transported from Lower Monumental Dam have had the lowest average post-Bonneville Dam survival. Average in-river survival from Lower Monumental Dam to Bonneville Dam has exceeded this average "D", indicating that fish not transported from Lower Monumental Dam have higher average annual SARs than fish transported from the site.

(3) For wild spring-summer chinook salmon, average post-Bonneville Dam survival for fish transported from Lower Granite Dam has roughly equaled the average survival of non-transported fish that migrated between Lower Granite and Bonneville Dams. Wild chinook salmon transported from Lower Granite Dam in 2000 had particularly low annual post-Bonneville Dam survival.

(4) For hatchery spring-summer chinook salmon and hatchery steelhead, average post-Bonneville Dam survival for fish transported from Lower Granite Dam has considerably exceeded the average estimated survival for the non-transported fish that migrated between Lower Granite and Bonneville Dams. (Data are not sufficient to judge for wild steelhead).

(5) It is very difficult to estimate annual D values precisely. For example, even with more than 2,000 returns of hatchery chinook salmon in 2000, a wide 95% confidence interval still existed (Table 22). The number of juvenile fish from the outmigration, however, provided the ability to make a relative precise estimate for survival for non-transported fish that migrated between Lower Granite and Bonneville Dams.

Table 21. Annual estimates of differential post-Bonneville survival (D) for Snake River wild spring-summer chinook salmon transported from various dams and for weighted average from all sites. Total adult returns are provided in parentheses (when 0 adults in a category, the number of juveniles is given as well). Non-transported PIT-tagged fish represent passage histories most representative of non-tagged fish that migrated to Bonneville Dam. All fish were tagged upstream from Lower Granite Dam. Approximate 95% confidence interval for weighted average given in brackets.

Year	Non-trans-ported	Transported all sites	Transported LGR	Transported LGO	Transported LMO
1994	(6)	0.683 (13) [0.254, 1.844]	0.770 (8)	1.187 (4)	0.239 (1)
1995	(10)	0.457 (8) [0.177, 1.184]	0.559 (7)	0.467 (1)	(0/195)
1996	(5)	1.081 (2) [0.202, 5.783]	0.688 (1)	2.453 (1)	(0/43)
1997	(17)	0.498 (4) [0.162, 1.539]	0.224 (2)	1.262 (2)	(0/14)
1998	(48)	0.430 (15) [0.238, 0.783]	0.480 (11)	0.334 (3)	0.421 (1)
1999	(104)	0.656 (48) [0.460, 0.934]	0.730 (32)	0.641 (9)	0.563 (7)
2000	(174)	0.336 (12) [0.184, 0.613]	0.245 (4)	0.474 (6)	0.274 (2)
		geometric mean: 0.553	**0.478**	**0.779**	**0.353**

Table22. Annual estimates of differential post-Bonneville survival (D) for Snake River hatchery spring-summer chinook salmon transported from various dams and for weighted average from all sites. Total adult returns are provided in parentheses (when 0 adults in a category, the number of juveniles is given as well). Controls are PIT-tagged fish with passage histories most representative of nontagged fish that migrated to Bonneville Dam in-river (control adults given in parentheses next to year label). All fish were tagged upstream from Lower Granite Dam. Approximate 95% confidence interval for weighted average given in brackets.

Year	Non-trans-ported	Transported all sites			Transported LGR		Transported LGO		Transported LMO	
1994	(7)	0.316	(6)	[0.104, 0.963]	0.314	(2)	0.445	(1)	0.468	(1)
1995	(32)	0.886	(20)	[0.501, 1.572]	0.808	(14)	1.238	(5)	0.661	(1)
1996	(32)	0.409	(6)	[0.168, 0.995]	0.780	(6)		(0/510)		(0/366)
1997	(185)	0.523	(233)	[0.430, 0.639]	0.561	(226)	0.469	(5)	0.517	(2)
1998	(336)	0.638	(885)	[0.561, 0.727]	0.829	(812)	0.405	(66)	0.319	(7)
1999	(736)	0.903	(1203)	[0.821, 0.993]	0.930	(697)	1.036	(481)	0.477	(25)
2000	(915)	0.870	(1426)	[0.798, 0.948]	0.961	(1030)	0.726	(310)	0.658	(86)

* 2 fish transported from McNary Dam returned as adults; estimated differential post-Bonneville Dam survival for McNary transport = 0.098.

Table 23. Annual estimates of differential post-Bonneville survival (D) for Snake River wild steelhead transported from various dams and for weighted average from all sites. Total adult returns are provided in parentheses (when 0 adults in a category, the number of juveniles is given as well). Controls are PIT-tagged fish with passage histories most representative of nontagged fish that migrated to Bonneville Dam in-river (control adults given in parentheses next to year label). All fish were tagged upstream from Lower Granite Dam. Approximate 95% confidence interval for weighted average given in brackets.

Year	Non-trans-ported	Transported all sites	Transported LGR	Transported LGO	Transported LMO
1994	(6)	0.531 (8) [0.178, 1.581]	0.663 (6)	0.211 (1)	0.266 (1)
1995	(1)	0.981 (1) [0.058, 16.710]	(0/287)	(0/66)	10.023 (1)
1996	(5)	0.978 (2) [0.181, 5.279]	0.678 (1)	2.214 (1)	(0/11)
1997	(4)	0.536 (3) [0.115, 2.492]	0.844 (3)	(0/44)	(0/23)
1998	(9)	0.118 (1) [0.014, 0.976]	0.165 (1)	(0/93)	(0/93)
1999	(18)	1.013 (12) [0.475, 2.163]	0.735 (6)	1.343 (4)	0.882 (2)
2000	(41)	0.691 (14) [0.368, 1.296]	0.660 (7)	0.801 (4)	0.613 (3)

Table 24. Annual estimates of differential post-Bonneville survival (D) for Snake River hatchery steelhead transported from various dams and for weighted average from all sites. Total adult returns are provided in parentheses (when 0 adults in a category, the number of juveniles is given as well). Controls are PIT-tagged fish with passage histories most representative of nontagged fish that migrated to Bonneville Dam in-river (control adults given in parentheses next to year label). All fish were tagged upstream from Lower Granite Dam. Approximate 95% confidence interval for weighted average given in brackets.

Year	Non-trans-ported	Transported all sites	Transported LGR	Transported LGO	Transported LMO
1994	(7)	2.707 (23) [1.140, 6.429]	3.684 (20)	(0/1007)	1.943 (2)
1995	(14)	0.435 (19) [0.214, 0.884]	0.392 (14)	0.996 (5)	(0/88)
1996	(17)	0.294 (4) [0.097, 0.896]	0.446 (4)	(0/353)	(0/94)
1997	(8)	0.968 (10) [0.374, 2.505]	1.615 (10)	(0/158)	(0/119)
1998	(26)	0.326 (7) [0.139, 0.767]	0.374 (5)	0.152 (1)	0.373 (1)
1999	(41)	0.332 (12) [0.171, 0.642]	0.336 (8)	0.457 (4)	(0/250)
2000	(41)	1.051 (14) [0.562, 1.967]	1.291 (13)	(0/102)	0.345 (1)

* In 1994, 1 fish transported from McNary Dam returned as an adult; estimated differential post-Bonneville Dam survival for McNary Dam transport = 0.417.

Temporal SARs for Spring Migrant Fish

The transportation evaluations based on PIT-tagged juvenile fish have provided information on variability in SARs within season. Not only do SARs vary over the course of the outmigration, but timing of the variation changes year to year. The transport group has the most fluctuation. For hatchery and wild spring-summer chinook salmon, SARs of transported fish generally increase as the season progresses, with a significant increase somewhere between mid-April to mid-May (Figures 14 and 15). For wild steelhead, we have only two years of data. Data from1999 shows the same pattern as for chinook salmon, but results from the 2000 study show the opposite, very high SARs right from the beginning with a dramatic decrease after the first week of May (Figure 16).

The SARs of non-transported fish also vary, but move in a general downward trend as the outmigration progresses (Figures 14 , 15, 16). The variation in both transport and non-transport SARs observed during this series of transport studies show that annual T/Is should not be used as the basis for management decisions. During periods when D exceeded the estimated juvenile survival of non-transported migrants, transported fish returned at higher rates than non-transported fish.

Temporal D Within Season

Snake River yearling migrants

Combining the temporal variability of SARs from transported and non-transported fish, and the relatively constant within-year survival estimated for non-transported fish, estimates of D vary temporally within season (Figures 17 - 19). During periods when the estimated value of D exceeded the estimated survival of non-transported fish, transported fish had higher return rates.

Upper Columbia River subyearling migrants

In both 1995 and 1996, subyearling chinook salmon transported from McNary Dam generally had higher return rates than non-transported fish when flows at the dam exceeded approximately 6,500 m3/second (approximately 225,000 cfs) and water temperatures remained below 18 ºC (Figures 20 and 21). These results suggest that transporting subyearling chinook salmon under conditions of higher water temperatures and lower flows decreases adult return rates compared to returning fish to the river. They also contrast to studies in the early 1980s conducted at the old juvenile facility at McNary Dam, where transported fish returned at 2 to 4 times the rate of fish released to the tailrace of the dam. In 2001 and 2002 we PIT-tagged subyearling chinook salmon at McNary Dam for additional transportation evaluations to determine if results from the 1995 and 1996 studies apply under the apparently improved ocean conditions that began in 1999.

Delayed mortality

We observed estimated annual D values of only 0.5 to 0.6 for wild yearling chinook salmon. This differential mortality of transported fish results in lower return rates of transported fish than expected from their direct survival. Given that estimates of adult return rates for the unmarked population of wild Snake River spring-summer chinook salmon in the last several have averaged nearly 4%, little room exists to presume any additional delayed mortality for the non-transported population. If a higher estimated D existed for transported fish, SARs for the population would increase. A change in transportation operations that increased D by 50% (from 0.55-0.60 to approximately 0.8) would also lead to nearly an equivalent increase in SARs, or to nearly 6% for spring-summer chinook. This value may reach the upper limit of possible adult returns. Any delayed mortality of the non-transported fish would increase this value even further. Thus, our conclusion that non-transported fish not experience delayed mortality (or have very little).

Results from the analyses of PIT-tagged fish with various detection histories in the hydropower system found no differences in return rates for wild chinook salmon or wild steelhead from either the 1999 or 2000 outmigrations (Figures 22 and 23). Hatchery adult returns continued to show a negative association with bypass history. For hatchery chinook salmon and steelhead, in several years, fish detected only at LGO, LMO, or MCN had significantly lower adult return rates than non-detected fish (Figures 24 and 25). Wild chinook salmon detected only at LGR in 1998 and 2000 had significantly higher adult return rates than non-detected fish (Figure 25). Juvenile survival estimates within the hydropower system appear nearly the same for wild and hatchery fish (Muir et al. 2001)and subsequent annual survival reports to BPA), indicating that any differential survival of hatchery fish occurred after they migrated below the hydropower system.

However, observations of differential adult return rates does not necessarily provide evidence that some bypass systems have more impact on fish than others or that the act of passing through bypass systems decreases fitness. Zabel et al. (In review)demonstrated that smaller fish are consistently detected at higher rates than larger ones at all three dams and for all fish groups examined (Figures 2 and 3). Coupled with the results from Zabel and Williams (2002) that larger spring-summer chinook salmon smolts return at higher rates than smaller ones, this may, at least partially, explain why multiple-bypassed fish return rates appeared lower than undetected ones in some years (Sandford and Smith 2002). However, the relationship between detection probability and fish length does not appear to bias survival estimates (Figure 4).

Selective Mortality

When we updated the results from Zabel and Williams (2002) by adding more years (1998 through 2000 for Snake River spring/summer chinook) and Snake River steelhead for 1999 and 2000, the main conclusions still held: return rates are strongly influenced by the size of individuals and the timing of their outmigration. Selectivity mortality based on fish length was generally not as strong in 1998 through 2000 as it was in 1995 and 1996 for spring/summer chinook salmon (perhaps due to better ocean conditions), although the level of length-based selective mortality was similar across years for transported wild fish (Figure 26, top plot). For the two years of data on return rates of steelhead, we observed strong length-based selective mortality, with all groups of steelhead incurring greater selective mortality than their chinook counterparts (Figure 26, top plot). Non-transported spring/summer chinook salmon that migrated earlier in the season typically returned at higher rates as demonstrated by negative selection coefficients ($P < 0.05$ for 4 out of 5 years for wild fish and 3 out of 5 for hatchery fish). While the magnitude of timing-based selection varied yearly for non-transported migrants, the pattern of variability was consistent among hatchery and wild chinook and steelhead, with strong selection in 1995, 1998, and 2000 and weaker selection in 1995 and 1999 (Figure 26, bottom plot). Timing-based selection was variable for transported fish, with fish transported early in the season returning at higher rates in some years, and fish transported later returning at higher in other years. Also, there was little consistency between wild and hatchery chinook salmon.

DISCUSSION

Snake River Wild Spring-summer Chinook Salmon

General

By any measure, Snake River spring-summer chinook abundance has increased dramatically in the last few years. We believe this is largely due a shift in ocean conditions, and that variability in ocean conditions is likely the most important driver of temporal patterns of abundance. However, the relative role of the hydropower system in overall stock performance is still uncertain. We do believe that improvements made to the hydropower system over the last three decades were crucial for preventing even more drastic declines during a period of poor ocean conditions and that impacts of the hydropower system are likely more important during poor ocean conditions. Unfortunately, we cannot reliably predict future ocean conditions, and thus we cannot rely on the persistence of good ocean conditions. With predictions of increased global warming in the near future, ocean conditions may actually become worse than any we have experienced. For these reasons, we must continue to assess the impacts of the hydropower system in the context of all impacts, including impacts occurring in both seawater and freshwater habitats.

Studies aimed at understanding the effects of the FCRPS have generally led to conclusions that return rates of fish from the mid-1970s through late 1990s did not meet the 2 to 6% SAR range deemed necessary for recovery of the listed stocks. With the exception of recruit/spawner analyses on the unmarked population that included adult returns through 1997/98, nearly all studies and analyses relied on results from fish PIT-tagged as juveniles and we now have evidence that PIT-tagged fish may return at lower rates than the untagged population. In recent years, a few groupings of PIT-tagged wild spring-summer chinook salmon attained SARs of 2%. From the 1999 and 2000 outmigrations, wild chinook salmon PIT-tagged at traps above Lower Granite Dam had SARs of 2.0 and 2.4%, respectively. Most other groupings of fish had lower returns. Based on estimates of historic SARs (catch + escapement), SARs of wild fish always exceeded those of hatchery fish (Figure 27). Somewhat surprisingly, in recent years estimated SARs of many groups of PIT-tagged hatchery fish have exceeded those of wild fish. For example, wild fish PIT-tagged above and transported from Lower Granite and Little Goose Dams in 1999 and 2000 had average SARs of 2.37 and 1.51%, respectively. For the same years, PIT-tagged hatchery fish had SARs of 2.83 and 2.63%, respectively. We hypothesize this results from PIT-tagging impacts on fish, with wild fish suffering greater impacts than larger wild fish. Within the wild chinook salmon category, evidence of a PIT-tagging effect exists. All SAR estimates for the composite population as a whole (1997 through 2003 complete adult returns) exceed SAR estimates based on PIT-tagged fish from those same years. Lower return rates for PIT-tagged fish compared to production releases were also found for some groups of fish used in the CSS evaluations (2003). Thus, we conclude that although PIT-tagged wild chinook salmon provide useful data when assessing the difference in return rates of different treatment groups, they do not provide good information on absolute adult returns of fish.

On the other hand, high SAR estimates for the unmarked population should not come as a surprise. As outlined in the introduction, they have varied historically (although we only have empirical estimates for Snake River fish since 1964). Further, unlike data derived from PIT-tagged fish, wild chinook SAR estimates based on the untagged population exceed the SARs of hatchery fish, as expected based on historical relationships. Williams and Matthews (1995) found that conditions in the hydropower system had improved tremendously from those that initially caused large losses of juvenile migrants (Raymond 1979). Williams et al. (2001) also found that survival of yearling Snake River chinook salmon through the present 8 dams of the mainstem FCRPS recently matched or exceeded those estimated to have occurred when the mainstem FCRPS had only 4 dams. Without actual measures of survival, but under the presumption of success from transportation, Raymond (1988) and Williams (1989) predicted that large returns of Snake River spring-summer chinook salmon could once again occur if ocean conditions improved. Based on recent research by Peterson and Schwing (2003), ocean conditions did change for the better in 1999. Already, based on returns in the last decade, the population growth rate [ln(brood year $_{\text{N = escapement over upper dam of the current brood year}}$ /brood year N–1 = escapement over the upper dam of brood year producing current brood year] has exceeded 1.0 for 6 straight years (the longest stretch since records began in the 1960s) (Figure 28). But, we do not know how long these improved conditions will last. Based on new modeling tools that predict adult returns based on ocean conditions juveniles encountered during their first several months at sea, we do at this time predict good adult returns from the juvenile outmigrations through 2003 (with adults returning through 2006) (Scheuerell In review). As stated, the earlier predictions of good returns depended not only on good ocean conditions, but also depended on favorable transportation of fish. We identified above that on an annual basis transported wild Snake River spring-summer chinook salmon have had return rates similar to fish that migrated through the hydropower system. Thus, they have an equivalent survival as high or higher than stocks that migrated through 4 dams in the hydropower system in the 1960s.

Transportation

As the recent annual survival estimates for Snake River yearling chinook salmon that migrate through the hydropower system have averaged near 50%, and typically 20-30% (sometimes as low as 1%) of the fish arriving at Lower Granite Dam do not get transported, transported fish provide more than 85% of the live smolts arriving below Bonneville Dam. Thus, clearly, the large majority of adult returns come from fish transported as juveniles. The data also clearly show transported fish have a differential survival (D) (they survive at lower rates) downstream of Bonneville Dam compared to fish that migrated through the hydropower system (they survive at higher rates). Further, and but more importantly, the data show the D-value changes throughout the migration season. When the D-value exceeds the estimated survival of fish migrating through the hydropower system, then transportation will return more fish. When it is lower, choosing not to transport fish may provide additional adult returns. Migration timing of transported fish appears the key.

Yearling chinook salmon transported by barge from Snake River dams arrive to their release point below Bonneville Dam typically in about 1.5 days while those that migrate through the 7 remaining dams take from 3 to 4 weeks early in the migration season to less than 2 weeks by the end of May (Smith 2000a, b, Zabel 2001). Thus, smolts marked at on the same day, but either transported or returned to the river most likely encounter different physical and biological conditions within the estuary and nearshore ocean upon their arrival. The Columbia River estuary and nearby ocean are very dynamic environments. Coastal winds, upwelling, currents, sea surface temperatures, and other physical conditions such as plume structure can change very quickly (Garcia Berdeal 2002). Large changes in biological conditions (such as forage fish abundance and predatory fish abundance) in the plume (Emmett 2000, 2001) and the estuary (R. L. Emmett, NOAA Fisheries, personal communication) have been observed between and within years. Growth and survival of salmonids in their first days and months at sea appear critical in determining overall salmonid year class strength. This is based on the relationship between returns of jack salmon with numbers of adults returning from the same brood class in later years, and between ocean purse seine catches of juvenile salmonids in June and subsequent jack and adult returns (Pearcy 1992).

Since transported fish generally enter the ocean 2 to 3 three weeks prior to non-transported fish, they most likely face greatly differing environmental conditions. Therefore, much of the observed seasonal average delayed mortality for transported fish could simply results from varying ocean conditions at their time of ocean entry. This comports with estimates of D observed in the Comparative Survival Study (CSS) where D was lowest for the earliest migrating stocks (Lookingglass and Dworshak hatcheries) and highest for the later migrants from McCall and Imnaha River acclimation ponds ((CSS) 2003).

This analysis of seasonal trends in post-Bonneville survival suggests that within-season variation could have important implications for management decisions, and that the implications are missed if this variation is ignored when only a single seasonal estimate of D is calculated. If the efficacy of transportation is largely determined by time of ocean entry, then delay of arrival below Bonneville Dam for early migrating stocks should increase their survival. Alternatively, for early migrating hatchery stocks, later hatchery release dates might lead toward a later arrival date at transport dams.

The smoltification process in salmonids causes morphological, behavioral, and physiological changes that affect downstream migration as well as the ability to survive in the marine environment. This process is regulated by developmental stage, photoperiod, and water temperature cues that enable salmonids to migrate when environmental conditions are most favorable for downstream passage and survival in the seawater environment (Folmar 1980, Wedemeyer 1980). The act of migration further stimulates smolt development (Zaugg 1985, Muir et al. 1994). Spring-summer chinook salmon and steelhead migrations in the Snake and Columbia Rivers show the same seasonal patterns each year, beginning in early April and tailing off near the end of May. Zaugg and Wagner (1973) found that gill Na^+-K^+ ATPase (an indicator of migratory readiness) and migratory urge declined at water temperatures of 13°C and above.

Steelhead that migrate too late in the season when water temperatures are above this threshold have a tendency to residualize. Although this same behavior has not been demonstrated in spring-summer chinook salmon, exposure to water temperatures above 13ºC has been shown to retard gill Na^{+}-K^{+} ATPase activity (Muir et al. 1994, Muir 2003). Construction of the FCRPS has altered the timing of smolt migrations. Regardless of when fish arrive at Lower Granite Dam, those not transported most certainly take longer to migrate through the entire FCRPS and arrive later at the ocean than they did historically. Further, transported fish cover the distance more quickly and arrive at the ocean sooner than they would have in an unregulated system.

The hypotheses that transportation induced stress or disease transmission (Budy et al. 2002) causes lower adult returns is not supported by the temporal variability in measured values of D and SARs. If these hypotheses held true, we would not expect to see the much higher SARs and D values later in the season. It appears more likely that early transported fish arrive too soon to the estuary. .

Although D values below 1.0 indicate a differential mortality between transported and non-transported fish, we expect that as some of the fish transported would die due to natural selection if they had continued their downstream migration through the hydropower system. Very low values of D, however, indicate a substantial delayed mortality after release from transportation barges. Aside from a differential morality between the upper dams on the Snake River from where they were transported (2% assumed), compared to fish that migrated to below Bonneville Dam (ca. 50% mortality), the two groups marked on the same day have substantially different timing to the ocean (a differential ranging from 20-25 days for the earliest fish to 15 days or less for the latest fish). This difference in timing likely accounts for D values greater than 1 often observed nearer the end of the migration period. We presume that the latest migrants leaving Lower Granite Dam miss the "window of opportunity" for the best survival conditions by arriving too late below Bonneville
Dam. Thus, on average, when the annual weighted D is matched with the average survival through the hydropower system, overall effective survival of fish downstream of Bonneville Dam meets or exceeds estimated values from the 1960s.

With the low number of adult returns of PIT-tagged fish to date, especially for wild fish, definitive conclusions are not possible. We tentatively conclude that D-values for fish transported from McNary Dam are lower than for dams farther upstream. Combined with the higher survival to Bonneville Dam for fish left in the river at McNary Dam, it appears that a spring transportation program at McNary Dam would provide marginal benefits (at best) to Snake River stocks. There is no evidence that D-values for chinook salmon transported from Little Goose Dam are lower than for fish transported from Lower Granite Dam.

Although annual SARs for fish PIT-tagged above Lower Granite Dam generally exceed those of fish PIT-tagged at Lower Granite, ratios (T/Is) of return rates for the transported compared to non-transported (non-detected) fish are similar. Thus, results from studies with fish PIT-tagged at Lower Granite Dam provide information on the relative differences in return rates of transported and non-transported fish in the population. The numbers of wild fish tagged above Lower Granite Dam that are estimated to arrive at the dam are very small, and the vast majority of these fish are bypassed back to the river; therefore, the SARs of transported and non-detected wild fish tagged above Lower Granite Dam have large standard errors. This makes statistical power very low to show differences in return rates among fish with different juvenile migration histories.

If D varies from location to location, a combination of strategies at different locations might maximize survival of migrants. For instance, if D is high for fish transported from Lower Granite Dam, but low for fish transported from dams farther downstream, it might make sense to choose configurations and operations to maximize collection and transportation of smolts at Lower Granite Dam, but to not collect and transport fish at downstream dams. This strategy would involve eliminating spill at Lower Granite Dam and spilling to cap and full bypass operations at all other dams. Options to change collection strategies at dams to potentially benefit spring chinook salmon, of course, may have no effect or negative effect for other species.

Flow, Temperature, and Migration Timing

The first fish PIT-tagged spring-summer chinook salmon to arrive at Lower Granite Dam had tended to have higher migration rates than PIT-tagged fish that arrived later at the dam (Figures 29 and 30). In contrast, these same fish that arrived earliest had lower migration rates through the hydropower system than fish that arrived later. Also the fish that arrived earliest at Lower Granite Dam from traps upstream of the dam took more time to migrate through the hydropower system than fish that arrived more slowly from the traps. In fact, surprisingly and contrary to nearly all previous results, where we have long constant periods within years with relatively steady flow, we found little relationship between migration rates and flow.

Differential Guidance and Implications to Results

The analysis of Zabel et al. (In review) clearly demonstrated a negative relationship between detection probability and fish size for juvenile Snake River spring-summer chinook salmon and Snake River steelhead. Their results show differential propensity for collection of small fish at dams. Thus, collected fish do not represent a random sample of the migrant population . This result coupled with the observation by Zabel and Williams (2002) (see also an update in Tables 25 and 26) that smaller juvenile salmon return at lower rates suggest that fish detected in juvenile bypass systems return at lower rates than non-detected fish. Thus, transportation evaluations of PIT-tagged fish marked above a dam, then collected and barged compared to non-detected fish serving as controls may produce biased results. Also, the observation that, for some years, multiply-detected fish return at lower rates than non-detected ones (Budy et al. 2002, Sandford and Smith 2002) may arise directly from differences in innate survival for different-sized fish passing through different routes at dams. The difference in sizes of fish are most pronounced for steelhead, and somewhat less for chinook.

Table 25. Sample size (*N*), mean length (mm) at tagging (standard error in parentheses) for the total tagged population and returning adults of Snake River spring-summer chinook salmon PIT tagged at Lower Granite Dam. δ is the selection coefficient (see text), and the *P*-value is based on a Monte Carlo test to determine if is greater than zero. If *P* < 0.05, then d is significantly greater than zero at the a = 0.05 level.

Release group	Total population		Returning adults		Percent return	δ	*P*-value
	N	Mean length (s.e.)	*N*	Mean length (s.e.)			
1995							
Non-transport W	5331	107.37 (0.112)	5	113.80 (3.441)	0.094	0.790	0.039
Non-transport H	21,596	136.55 (0.119)	62	143.95 (2.200)	0.287	0.422	0.001
Transport W	3369	106.84 (0.140)	12	110.17 (2.873)	0.356	0.409	0.079
Transport H	15,583	136.17 (0.139)	93	141.62 (1.301)	0.597	0.315	0.002
1996							
Non-transport W	13,92	109.31 (0.07)	7	115.00 (1.83)	0.050	0.741	0.023
Non-transport H	53,420	139.45 (0.06)	53	146.59 (2.31)	0.099	0.479	0.001
Transport W	8656	110.49 (0.08)	10	113.00 (1.50)	0.116	0.351	0.139
Transport H	36,867	139.62 (0.07)	53	146.30 (2.14)	0.144	0.477	0.001
1998							
Non-transport W	8676	113.01 (0.07)	53	113.75 (0.82)	0.611	0.115	0.208
Non-transport H	61,541	135.72 (0.05)	229	135.43 (0.75)	0.372	-0.02	0.643
Transport W	5476	111.97 (0.09)	33	114.09 (1.13)	0.603	0.306	0.036
Transport H	38,773	135.95 (0.06)	243	136.73 (0.67)	0.627	0.062	0.169
1999							
Non-transport W	11,827	109.38 (0.08)	152	110.20 (0.58)	1.285	0.099	0.106
Non-transport H	61,491	137.82 (0.05)	891	139.29 (0.43)	1.449	0.114	0.001
Transport W	8,113	109.43 (0.09)	172	111.05 (0.56)	2.120	0.196	0.004
Transport H	43,169	138.16 (0.06)	866	138.71 (0.37)	2.006	0.042	0.110
2000							
Non-transport W		110.38 (0.03)	165	111.37 (0.27)	1.410	0.139	0.000
Transport W	15414	109.77 (0.06)	261	111.41 (0.43)	1.693	0.228	0.000

Table 26. Sample size (*N*), mean release day of the year (standard error in parentheses) for the total tagged population and returning adults of Snake River spring-summer chinook salmon PIT tagged at Lower Granite Dam. δ is the selection coefficient (see text), and the *P*-value is based on a Monte Carlo test to determine if is greater than or less than zero. If $P < 0.05$, then d is significantly greater or less than zero at the a = 0.05 level.

Release group	Total population		Returning adults		Percent return	δ	*P*-value (two-tailed)
	N	Mean release date (s.e.)	*N*	Mean release date (s.e.)			
1995							
Non-transport W	31,766	119.81 (0.10)	63	114.81 (1.94)	0.198	-0.290	0.007
Non-transport H	104,279	121.06 (0.03)	321	118.42 (0.43)	0.308	-0.268	0.000
Transport W	21,359	119.84 (0.10)	78	125.77 (2.07)	0.365	0.410	0.000
Transport H	81,780	120.95 (0.03)	455	122.29 (0.40)	0.556	0.143	0.001
1996							
Non-transport W	14,078	117.62 (0.09)	7	116.43 (4.27)	0.050	-0.112	0.427
Non-transport H	53,976	126.52 (0.04)	53	126.23 (1.97)	0.098	-0.030	0.416
Transport W	8699	117.80 (0.11)	10	114.5 (2.62)	0.115	-0.314	0.167
Transport H	37,027	126.09 (0.05)	53	125.68 (1.41)	0.143	-0.042	0.382
1998							
Non-transport W	8,714	111.93 (0.13)	53	103.79 (1.14)	0.608	-0.687	< 0.001
Non-transport H	61,853	114.55 (0.04)	230	109.17 (0.61)	0.372	-0.481	< 0.001
Transport W	5,496	111.83 (0.16)	34	106.09 (1.44)	0.619	-0.499	< 0.001
Transport H	39,032	114.96 (0.06)	245	116.86 (0.68)	0.628	0.174	0.004
1999							
Non-transport W	11,853	118.79 (0.13)	152	116.65 (0.73)	1.282	-0.148	0.029
Non-transport H	61,742	121.88 (0.04)	892	121.67 (0.29)	1.445	-0.023	0.242
Transport W	8128	119.88 (0.14)	172	121.11 (0.75)	2.116	0.098	0.101
Transport H	43,305	122.74 (0.04)	867	125.37 (0.27)	2.002	0.296	< 0.001
2000							
Non-transport W	43,241	124.55 (0.08)	610	119.29 (0.51)	1.411	-0.331	< 0.001
Transport W	15,535	120.37 (0.13)	261	118.97 (0.89)	1.680	-0.087	0.078

Effects of Changing Ocean Conditions

Increasing evidence points to dramatic changes in the marine ecosystem of the northern Pacific Ocean resulting from shifts in climate over the past 2000 years (Finney et al. 2002, Moore et al. 2002). Throughout this region, changes in ocean-climate conditions have influenced zooplankton, benthic invertebrate, seabird, and fish populations (McGowan et al. 1998). In particular, analyses of data from the last 100 years demonstrate a strong relationship between ocean conditions and the production of Pacific salmon (Oncorhynchus spp.) across a range of spatial and temporal scales (Mantua et al. 1997, Beamish et al. 1999). The varied response of salmon to these past environmental changes likely reflects their complex life history and the wide diversity of freshwater and marine habitats that they occupy (Hilborn et al. 2003).

Recent evidence links chinook salmon from the Columbia River basin to cyclic changes in ocean-climate conditions. Modeling exercises directed at explaining the negative effects of various anthropogenic activities on the productivity of Snake River spring-summer (SRSS) chinook salmon identified the estuary and ocean environments as important sources of unexplained variation in stock performance (Kareiva et al. 2000, Wilson 2003). Using catch records from commercial fisheries, Botsford and Lawrence (2002) found reasonable correlations between the inferred survival of Columbia River chinook salmon and physical attributes of the ocean, such as sea-surface temperature and coastal upwelling. Building upon these previous studies, Scheuerell and Williams (in review) found that they could actually forecast changes in the smolt-to-adult survival of SRSS chinook from changes in coastal ocean upwelling over the past 37 years, including the rapid decline in the 1960-70s and the increase in the late 1990s . All of these analyses highlight the important effects of the ocean in determining smolt-to-adult survival, and further support Pearcy's {, 1992 #307}assertion that the primary influence of the ocean on salmon survival occurs early within the first year that juveniles occupy coastal waters.

Diversity

NOAA Fisheries defines a viable salmonid population as “an independent population of any Pacific salmonid (genus *Oncorhynchus*) that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100-year time frame” (McElhany 2000). Genetic diversity is important because it protects a species by allowing a wider use of environments, protects against short-term spatial and temporal environmental changes, and provides the raw material for surviving long-term environmental change (McElhany 2000). To this end, the NOAA Fisheries believes it necessary to “limit or remove human-caused selection or straying that weakens the adaptive fit between salmonid population and its environment or limits a population’s ability to respond to natural selection” (McElhany 2000). Human-caused selection can occur throughout the salmonid life cycle.

The Independent Scientific Group recommends that “Because the full assemblage of salmonids in the Columbia River basin probably used many migration strategies”, a diversity of management schemes should be used to assist migration. Without diversity of management, there is likely to be further stock selection" (ISG 1996). Fish bypass systems, spillways, the use of transportation, flow augmentation, and other management strategies may select for particular stocks or life histories and could therefore reduce diversity if used exclusively. Certainly, for wild spring-summer chinook salmon, early migrants do not appear to fare as well from transportation as later migrants.

Therefore, in their review of transportation, the Independent Scientific Advisory Board concluded that "Spreading the risk of negative outcomes among alternative routes of hydroelectric passage is advisable to prevent a recovery action designed for one listed species from becoming a factor in the decline of another species", and "in the face of uncertainties associated with potential negative effects of transportation on genetic and life history diversity"(ISAB 1998).

In light of the Hilborn et al. conclusion (2003) that the overall Bristol Bay sockeye salmon population has remained at a high level specifically due to diversity of populations, effects to ensure diversity in listed Columbia River stocks is warranted.

Snake River Steelhead

General

Recent SAR estimates for the non-tagged population of wild Snake River steelhead do not exist. The weighted average SAR for wild fish from the combined 1999 and 2000 outmigrations based on PIT-tag returns from juveniles marked at Lower Granite Dam was 4.0 (NOAA Fisheries unpublished data). These returns were not adjusted for harvest or any potential (but unknown effects of tagging). As indicated above, however, the 2001 to 2003 median return of wild steelhead increased, on average, more than 4-fold over the previous 10 years. The 2000 return (adults from outmigrations in 1998 and 1999) doubled over the previous 10-year average. Thus, presumably, steelhead SARs had similar magnitudes of increase, as no apparent increase in wild smolts occurred over that short period. The median estimated SAR for the composite wild steelhead population (escapement to Lower Granite Dam as basis) for outmigrations from 1990 through 1994 was 1.23% (range 1.05 to 2.38%) (Petrosky 1998 - November 30). Expanding this value based on the ratio of increase in wild adult returns to the Snake River in the most recent 3-years compared to those in the 1990s would result in SAR estimates for recent years in the neighborhood of 5.5%.

The low spawning populations in the 1990s (some the lowest in the last 35 years) produced comparatively low numbers of wild smolts compared the 1960s. Thus, even with the recent large increases in adult returns, total adult returns of wild fish remain at only approximately one-half the level of the 1960s.

Transportation

As with wild spring-summer chinook salmon, transportation plays a huge role in adult steelhead returns. In general, 85% or more of the wild untagged steelhead smolts get transported. A small percentage migrate through the river. These have only moderate survival. Thus, likely greater than 95% of live steelhead smolts immediately downstream of Bonneville Dam arrived via transportation. As with yearling chinook salmon, timing of transportation makes a difference. However, unlike chinook salmon, steelhead transported early in the season have high return rates, whereas those transported after mid-May in recent years have produced few adults. Thus, measures of annual D have little value. Further, transporting juveniles provides large benefits for steelhead. This likely results to some degree from steelhead choosing not to continue to migrate after they have spent some time within the hydropower system. Thus, decisions to delay initiation of transportation to benefit yearling chinook salmon will probably have large negative consequences for steelhead.

Further, annual estimates of D for hatchery steelhead transported from Lower Granite Dam have consistently been higher than for those transported from locations farther downstream. This suggests that increased transportation of hatchery steelhead from Lower Granite Dam will lead to increased adult returns (compared to fish not transported). There are too few data to predict whether increased transportation of wild steelhead would also lead toward higher return rates.

Flow, Temperature, and Migration Timing

Steelhead also respond to flow differently than yearling chinook salmon (Smith et al. 2002). Their migration responds much more closely to changes in flow. Further, as the migration season progresses, estimates of steelhead survival decrease. This may relate to either an increased loss of steelhead to predators, or a decreased propensity of steelhead to migrate as water temperatures warm. As stated above, the smoltification impacts steelhead migration. Steelhead migrations declined at water temperatures of 13°C and above. Steelhead that migrate too late in the season when water temperatures are above this threshold have a tendency to residualize.

The extremely poor Snake River steelhead survival observed in 2001 was in part due to avian predation, particularly in the Lower Monumental Dam tailrace to McNary Dam tailrace reach. Of the PIT-tagged steelhead smolts leaving Lower Monumental Dam in 2001, more than 21% were later detected on McNary Dam reservoir bird colonies (Table 7). Although flow conditions improved in 2002 and 2003, substantial avian predation on steelhead has continued in this reach (Zabel 2002, Ryan et al. 2003). The steelhead population downstream of Lower Monumental Dam consists almost entirely of PIT-tagged fish, as collection/bypass system have high efficiency rates and most non-tagged fish get transported. Although most PIT-tagged fish get returned to the river at collection facilities, factors affecting downstream PIT-tagged migrants below Lower Monumental Dam have small effects on the aggregate population.

Snake River Fall Chinook Salmon

General

As with yearling chinook salmon and steelhead, the estimated adult returns of natural origin fall chinook salmon to above Lower Granite Dam have increased in recent years more than 4-fold over levels seen from outmigrations in the 1990s. Total numbers of fall chinook salmon over Lower Granite have also increased tremendously, but much of this increase results from large releases of Lyons Ferry Hatchery fish above the dam. Nonetheless, estimates of wild fish have, to the degree possible, taken into account the large increases in hatchery fish. Total numbers of natural origin fish above Lower Granite dam in recent years have exceeded all levels observed since the completion of the dam in 1975. The two periods are likely not comparable, however, as harvest rates on fall chinook have changed substantially in recent years, owing to ESA listing of some Columbia River fall chinook stocks.

Transportation

Little is known about the effects of transportation on these fish. Studies to evaluate transportation of these Snake River fish began only a couple of years ago. As bypass systems are set to return only PIT-tagged fish to the river, few fish in the general population get transported. The annual adult return of transported fish, with which we could compare non-transported fish, has only averaged about 4 fish since 1995. Thus, comparing percentages of returns has little value. Nonetheless, comparisons of percentages between transported fish (1 fish here, 1 fish there) against non-transported fish indicates little difference in return rates. From these data, we have two general conclusions. First, transportation of fall chinook neither greatly harms nor helps the fish, and thus transportation is consistent with a “spread the risk” strategy. Also, if the T:I ratio is close 1, then an annual estimate of D would approximately equal the survival of non-transported fish (a value that, to date, we have not estimated due to a combination of low numbers of released PIT-tagged fish, low detection efficiencies at dams downstream of McNary Dam, and no operation of the 2-boat trawl in the lower river during the summer). Thus, it appears that the annual value of D used in the Biop (0.2) is reasonable, albeit highly uncertain. As noted below, fall chinook salmon do not have a completed directed migration, so our measure of downstream survival over the reaches possible, only relates to active migrants. We don’t have a good measure of survival for fish that didn’t initially migrate. Thus, it is not clear how an estimated D derived from the actively migration population actually applies to population of fish that do not migrate as quickly. We hope to have much more precise evaluations of transportation in the next few years.

Flow, Temperature, and Migration Timing

Migration of Snake River fall chinook is not as directed as that of spring chinook. Some percentage chose not to migrate until after water temperatures cool in September, while some do not migrate until the next spring. From the population of fish PIT-tagged between 1995 and 2000, 46,773 fish were detected passing either Lower Granite, Little Goose, or Lower

Monumental Dam prior to 1 September of each year, while 5,301 were detected after 1 September. Of these, those that migrated early produced 142 adult returns, while those that migrated late produced 73, for comparative SARs of 0.32 and 1.29% respectively. Of all fish we PIT tagged over this time period, nearly two-thirds were not detected. Based on CJS survival estimates, a large number apparently died before ever reaching Lower Granite Dam. For fish detected the first time after 1 September, we do not know what proportion of the population the live fish represented. Certainly, they came from some large population.

Snake River Sockeye Salmon

We have little information about these fish with regard to transportation. We did observe in 2003 that survival of juveniles from release to Lower Granite Dam was quite low, as follows:

Hatchery	Release site	Number released	Survival to LGR	Survival to MCN
Sawtooth	Pettit Lake	2,013	0.444 (0.021)	0.308 (0.044)
Sawtooth	Redfish Lake	1,015	0.116 (0.016)	0.068 (0.023)
Bonneville	Alturus Lake	1,481	0.034 (0.017)	0.008 (0.003)
Bonneville	Pettit Lake	1,565	0.345 (0.024)	0.191 (0.047)
Bonneville	Redfish Lake	1,007	0.068 (0.015)	0.023 (0.008)

CONCLUSIONS/SUMMARY

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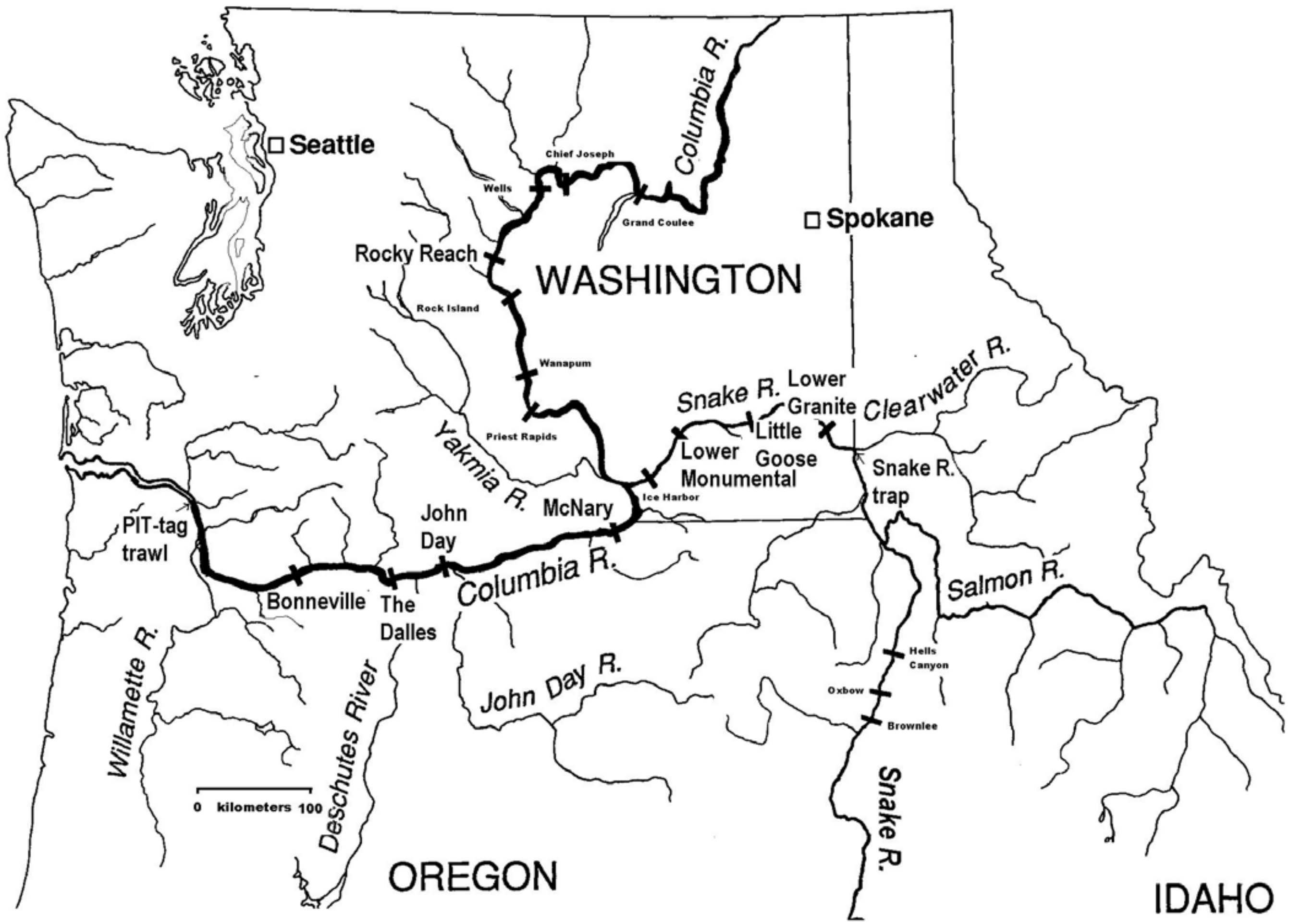


Figure 1. Map of Columbia River basin showing major dams. PIT-tag detection sites at traps, dams, and trawls in large type.

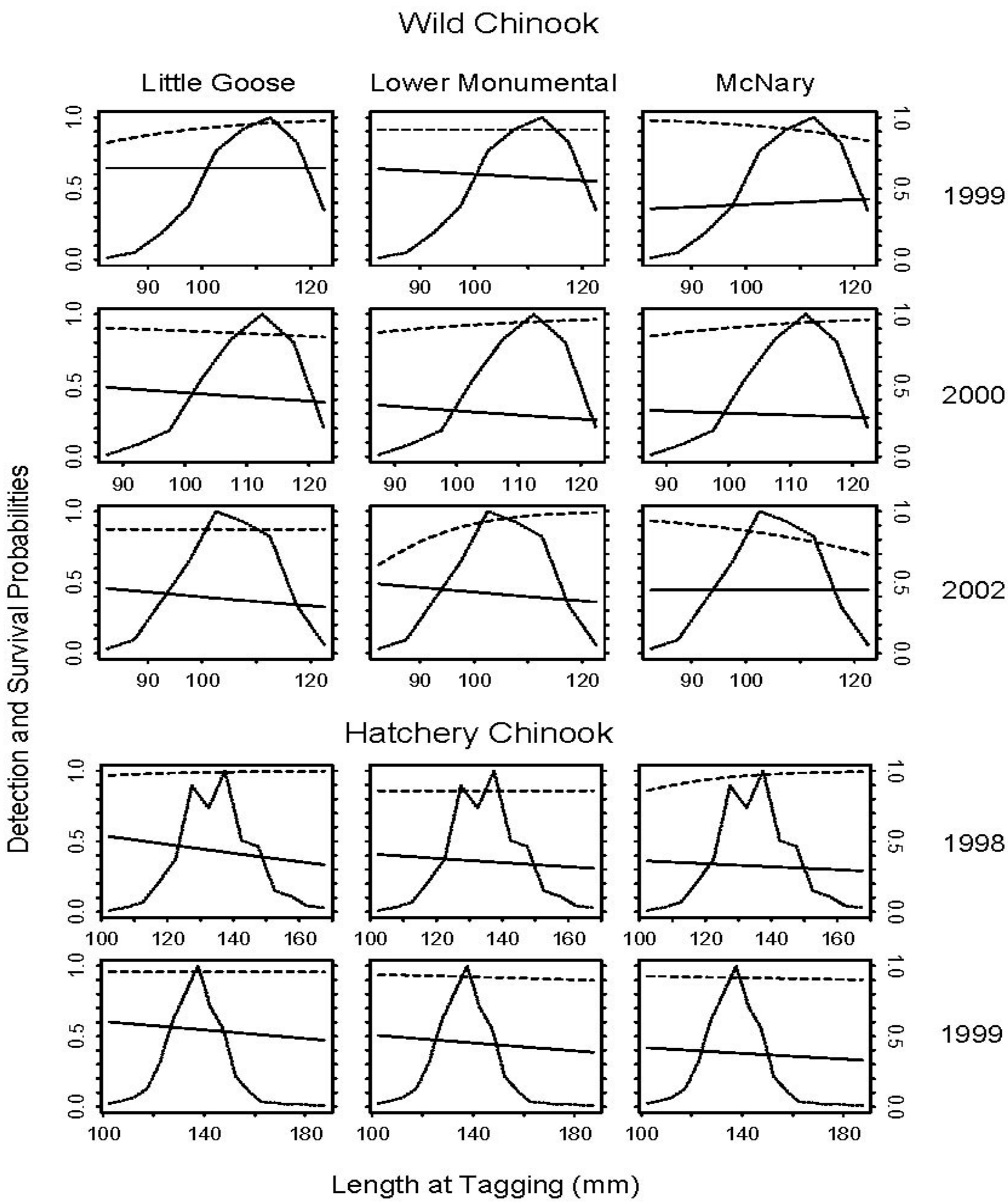


Figure 2. Relationships between detection (solid line) and survival (dashed line) probability and fish length (mm) for Snake River spring/summer chinook salmon released at Lower Granite Dam. The dotted line is the distribution of lengths in 5 mm increments and scaled such that the length class with the most fish is given a value of 1.0. Details of the analysis are provided by Zabel et al. (*In Review*).

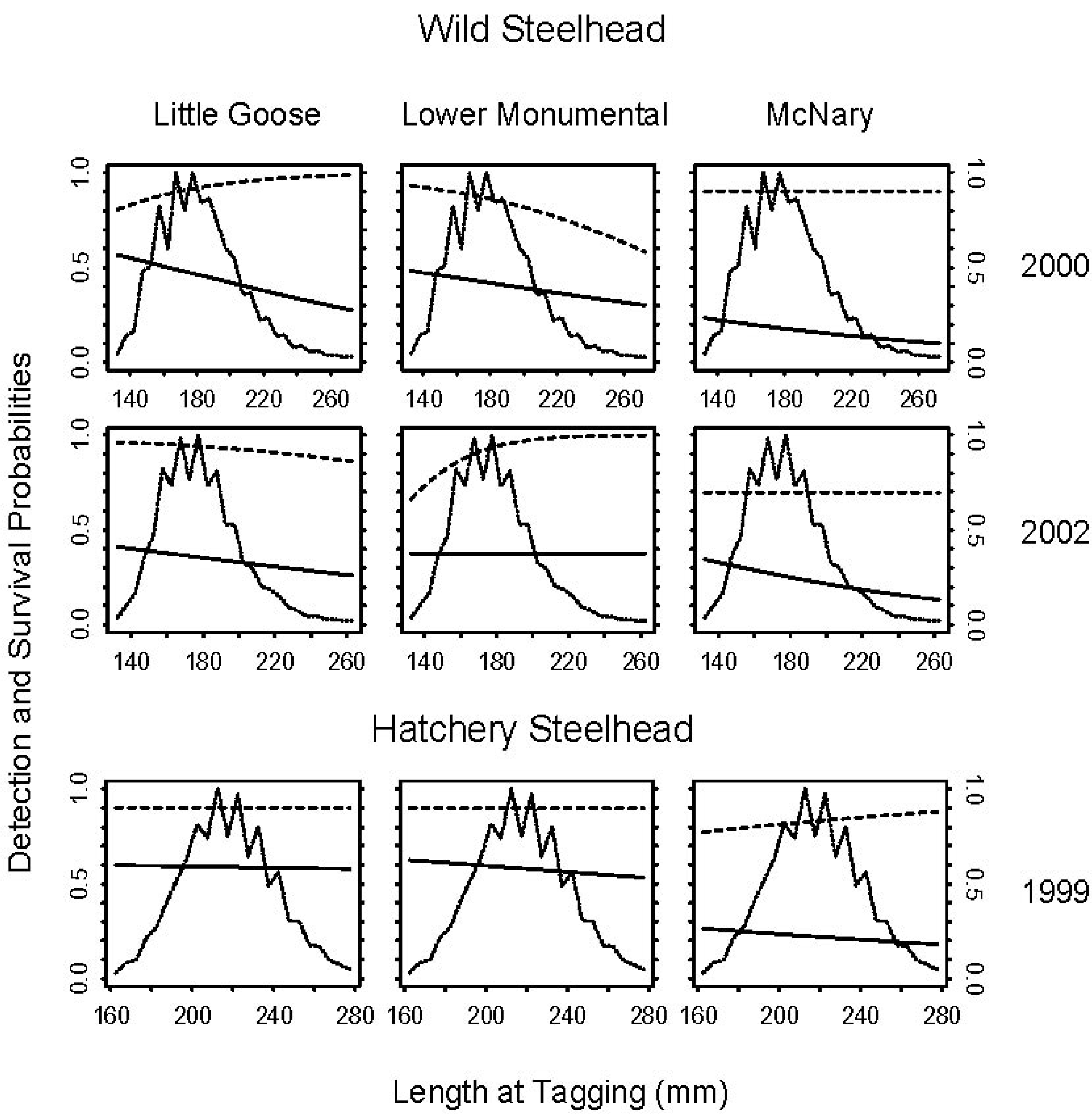


Figure 3. Relationships between detection (solid line) and survival (dashed line) probability and fish length (mm) for Snake River steelhead released at Lower Granite Dam. The dotted line is the distribution of lengths in 5 mm increments and scaled such that the length class with the most fish is given a value of 1.0. Details of the analysis are provided by Zabel et al. (*In Review*).

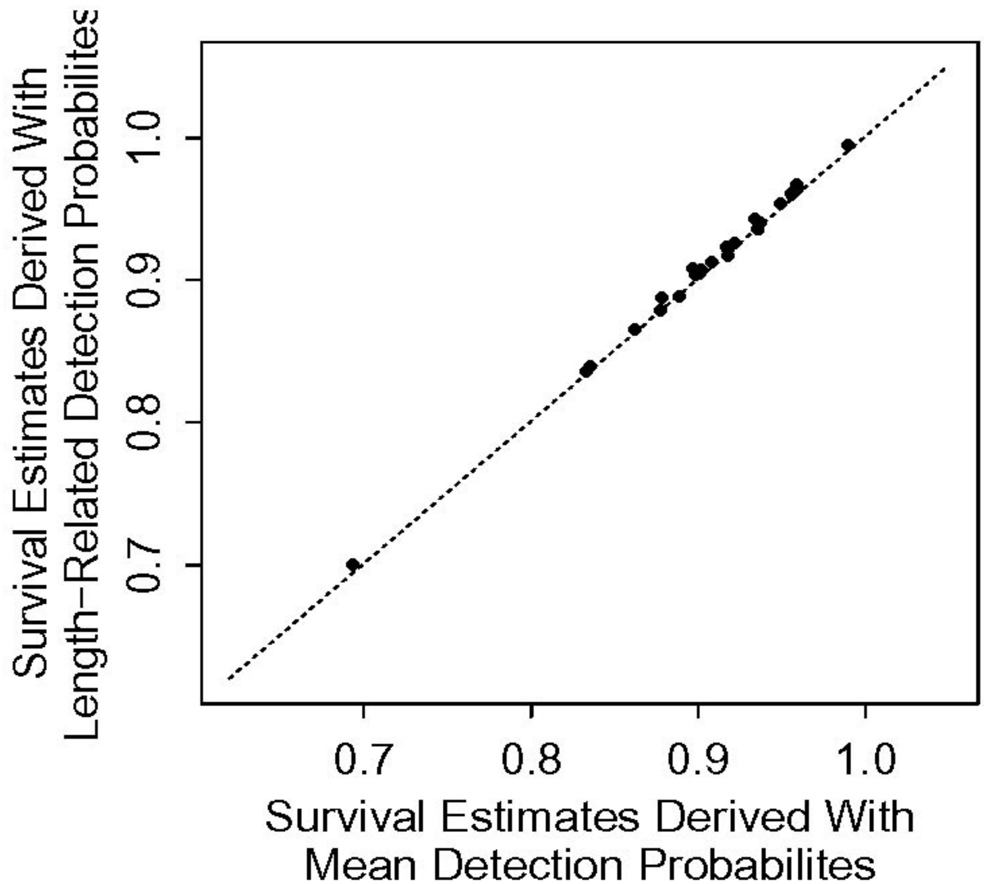


Figure 4. Comparison of survival estimates derived assuming mean detection probabilities (Cormack-Jolly-Seber method) and those using length-related detection probabilities (Zabel et al. *In Review*). Wild and hatchery spring/summer chinook salmon and steelhead were tagged and released at Lower Granite Dam (1998-2002), and survival was estimated from Lower Granite to Little Goose Dam, Little Goose to Lower Monumental Dam, and Lower Monumental to McNary Dam. The dashed line is the one-to-one line.

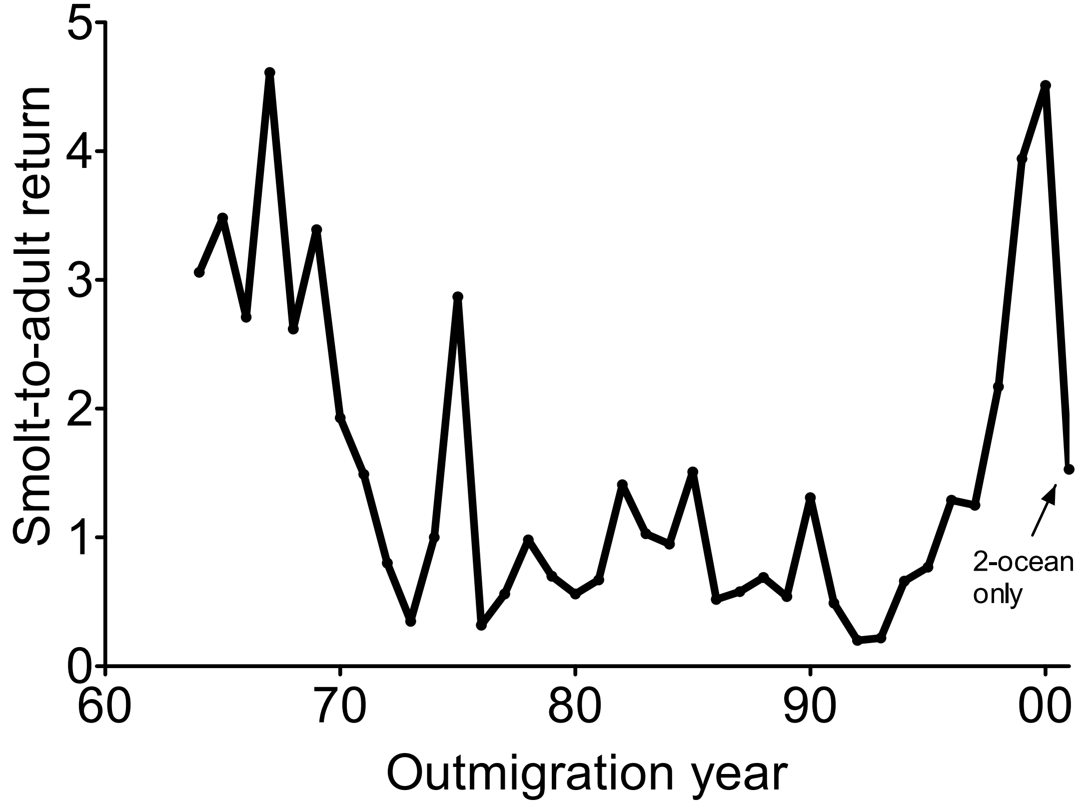


Figure 5. Estimated smolt-to-adult (SAR) return rates from upper dam on the Snake River for the composite marked and unmarked population of wild spring-summer chinook salmon, by juvenile outmigration year. Adults include counts at the upper Snake River Dam (Ice Harbor through 1968, Lower Monumental 1969, Little Goose 1970 - 1974, and Lower Granite 1975 - present) plus the estimated catch in fisheries downstream from the Snake River.

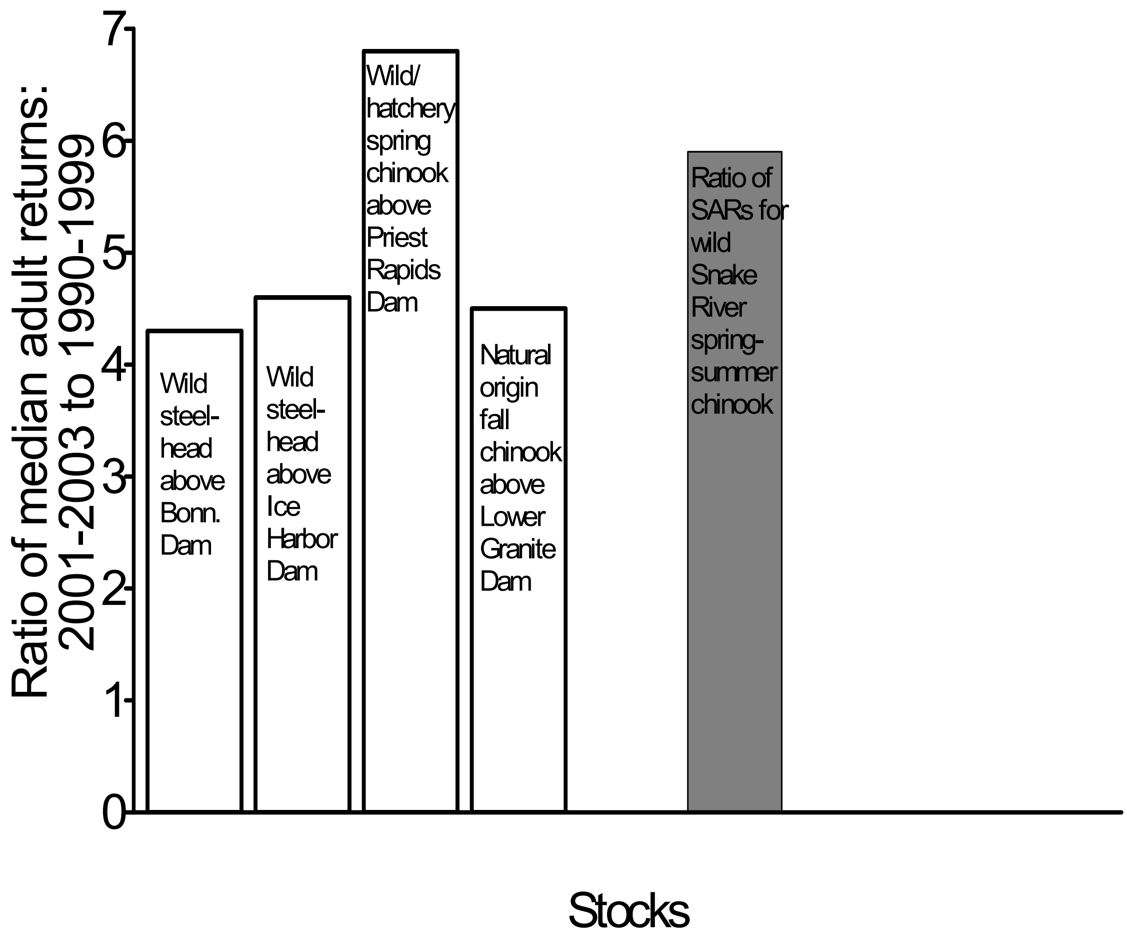


Figure 6. Ratio of median adult return between 2001 and 2003 to median adult return between 1990 and 1999 for several stock groupings of fish above Bonneville Dam compared to the ratio of SARs for wild Snake River spring-summer chinook salmon

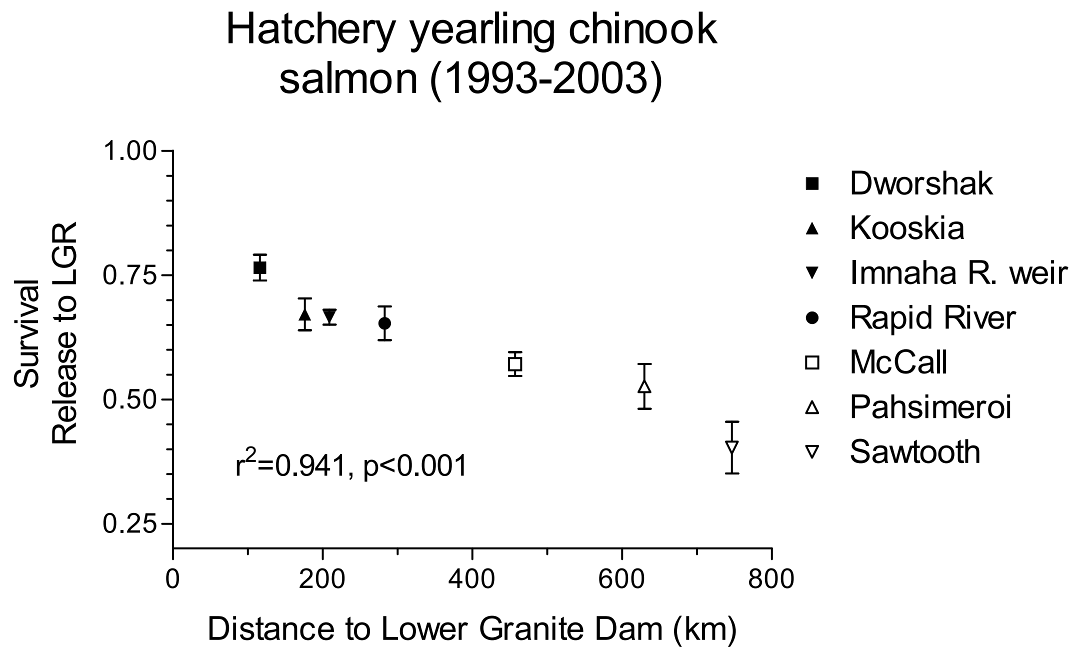


Figure 7. Estimated survival with standard errors from release at Snake River Basin hatcheries to Lower Granite Dam tailrace, 1993-2003 vs distance (km) to Lower Granite Dam. The correlation between survival and migration distance is also shown.

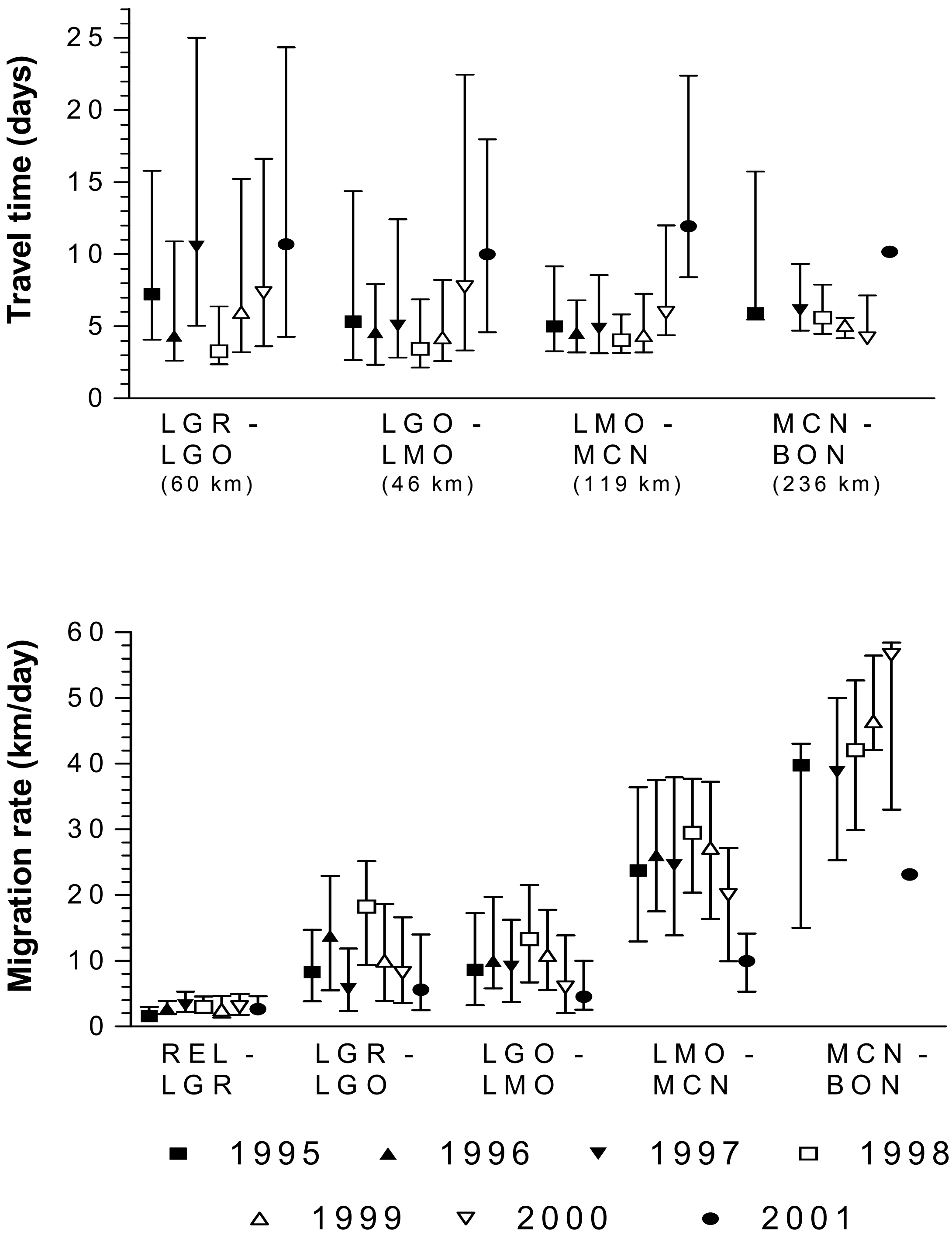


Figure 8. Median travel times and migration rates (with 20th and 80th percentiles) for PIT-tagged hatchery fall chinook salmon, 1995-2001. Rel, release site in the Snake River; LGR, Lower Granite Dam; LGO, Little Goose Dam; LMO, Lower Monumental Dam; MCN, McNary Dam; and BON, Bonneville Dam. The lengths of the reaches are given in parentheses in the upper pannel.

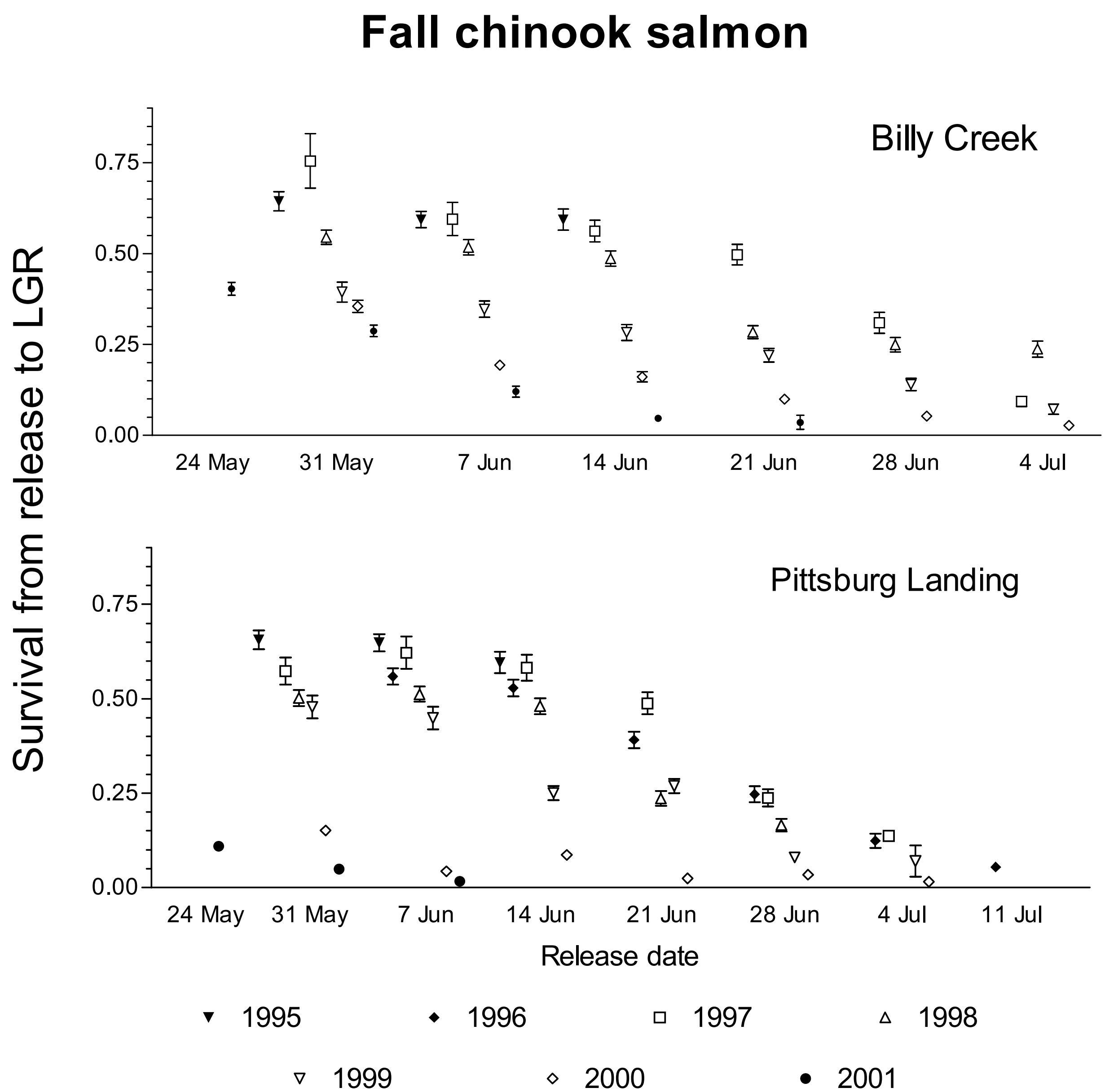


Figure 9. Estimated survival probabilities (with standard errors) from point of release in the Snake River (Billy Creek or Pittsburg Landing) to the tailrace of Lower Granite Dam for PIT-tagged hatchery fall chinook salmon, 1995-2001.

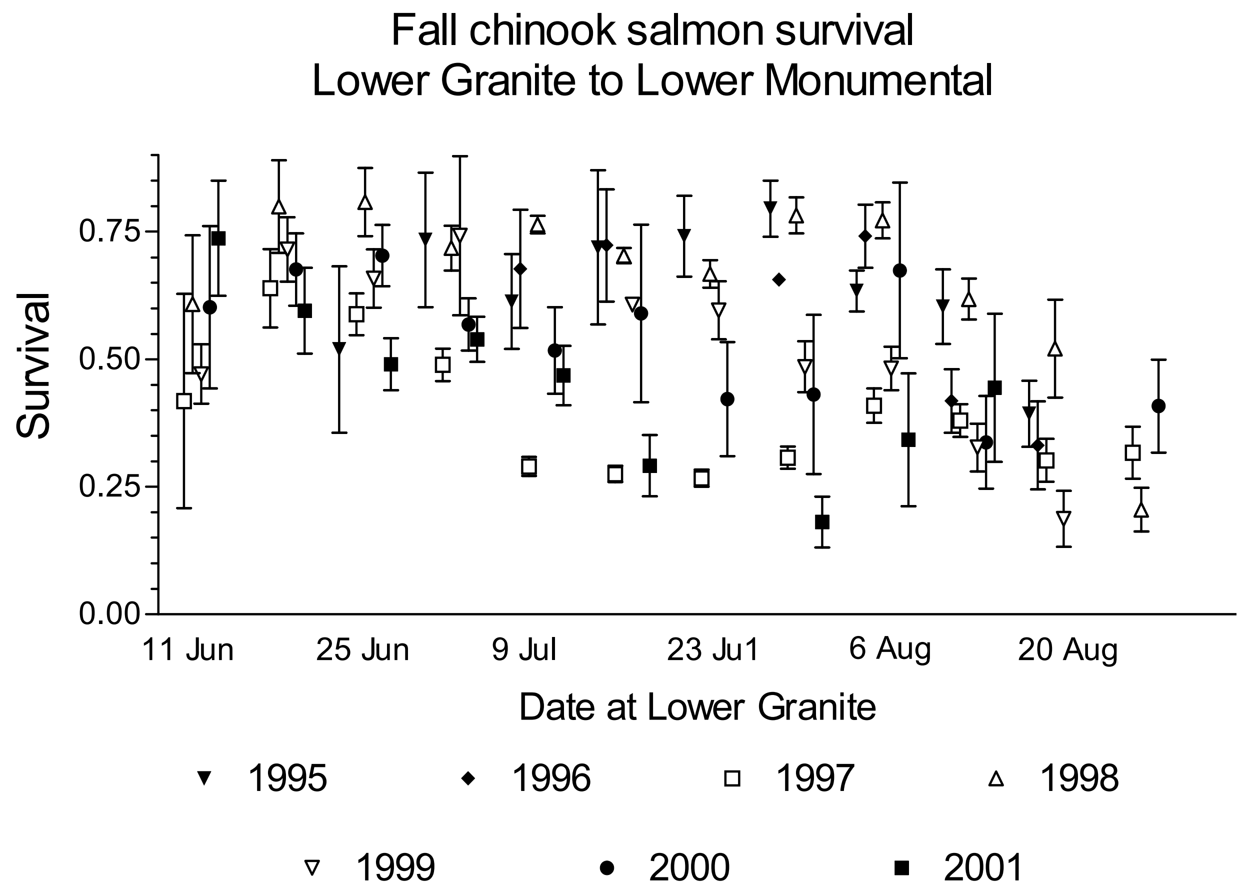


Figure 10. Estimated survival probabilities (with standard errors) to the tailrace of Lower Monumental Dam for PIT-tagged hatchery fall chinook salmon leaving Lower Granite Dam, by week, 1995-2001.

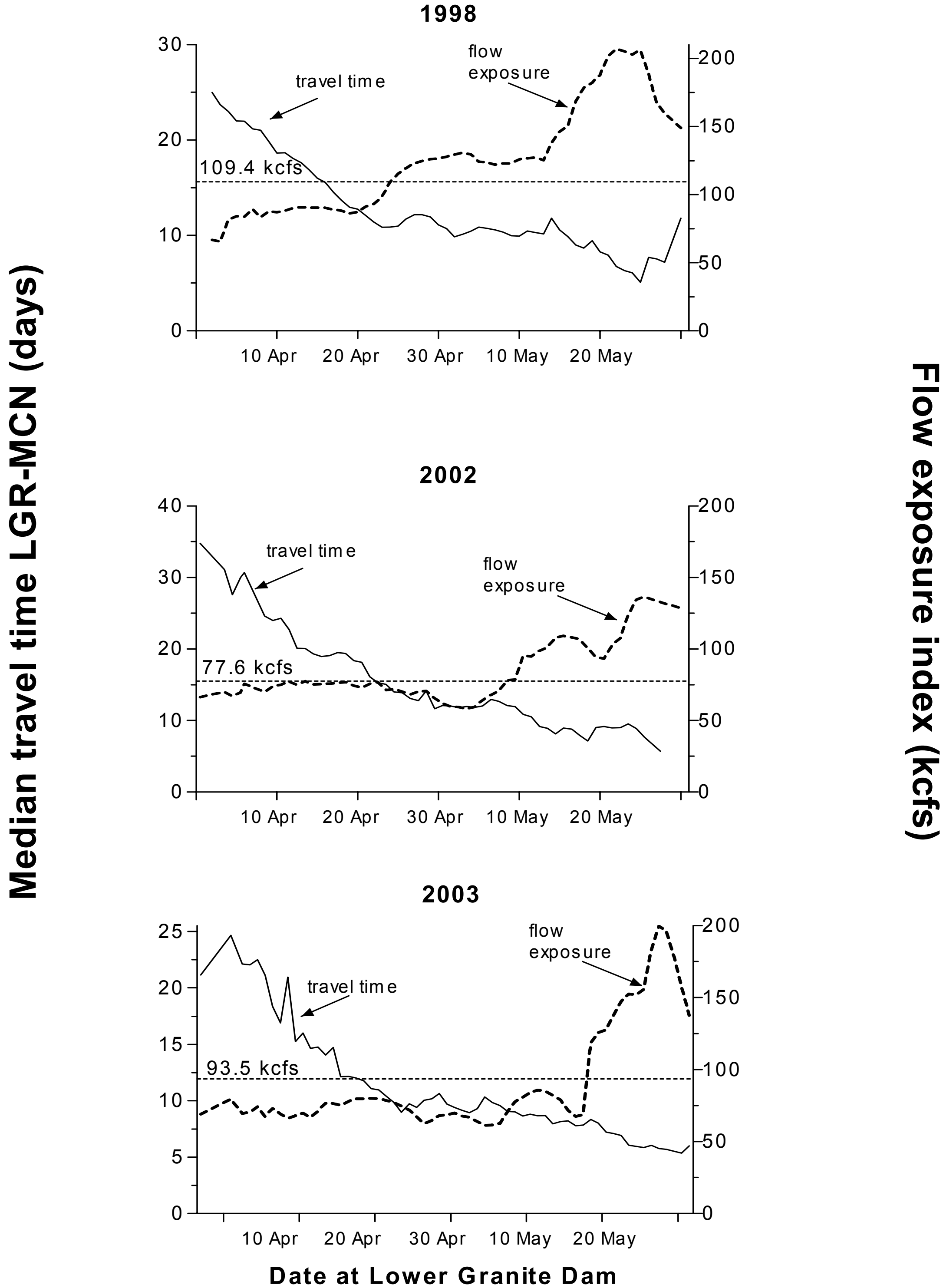


Figure 11. Median travel time and flow exposure index plotted against date for daily groups of yearling chinook salmon leaving Lower Granite Dam, 1998, 2002, and 2003. Dashed horizontal line is weighted average flow exposure index.

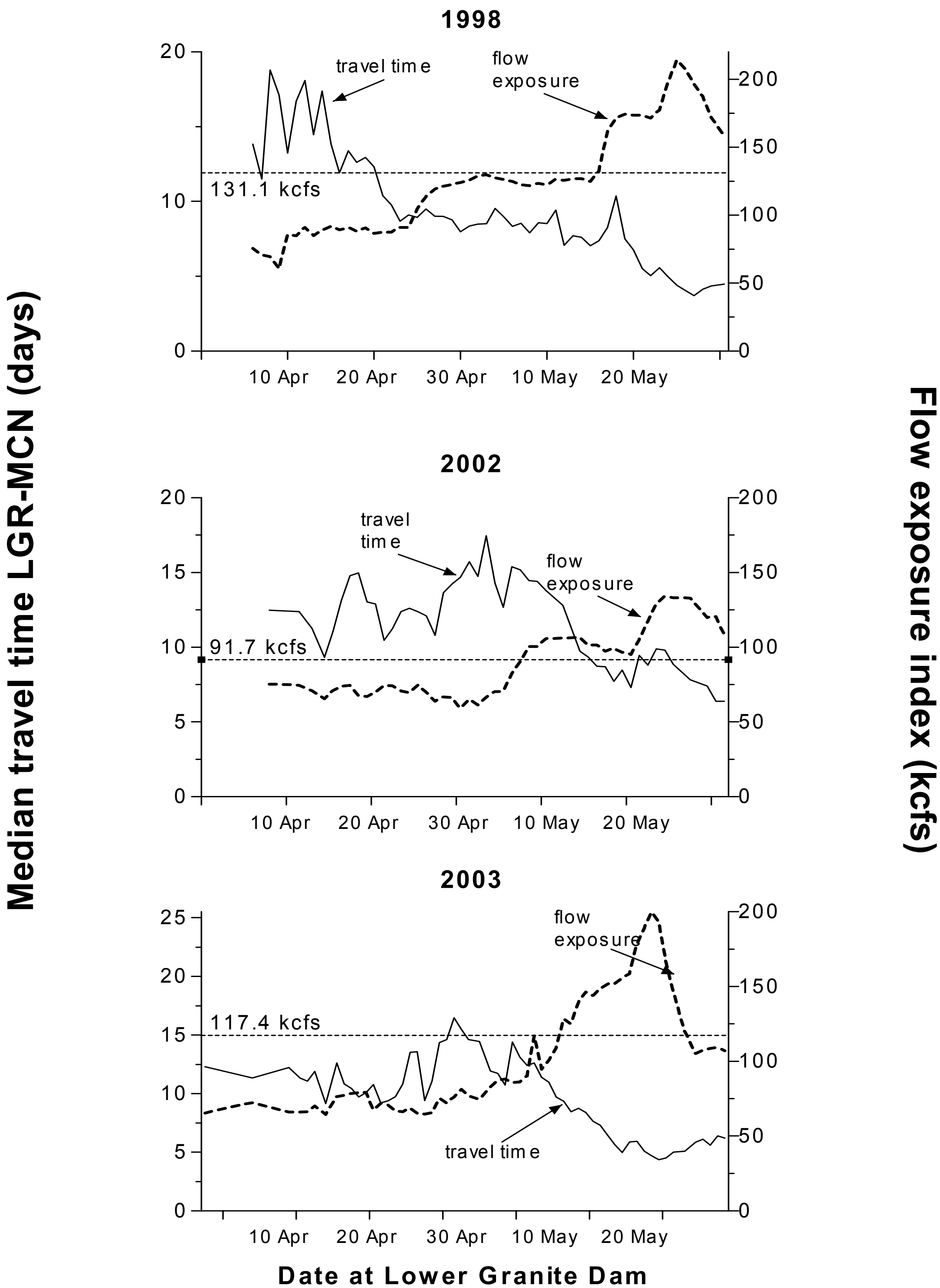
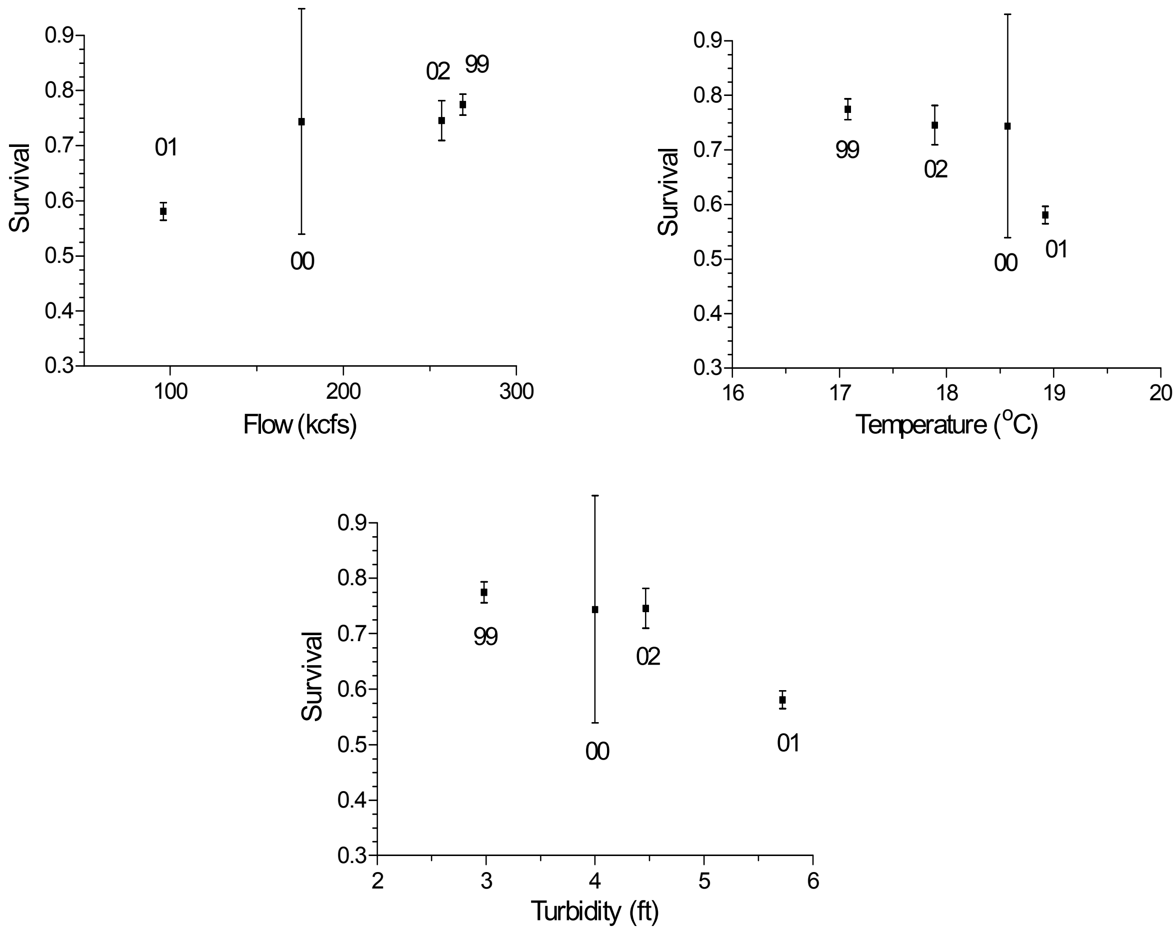


Figure 12. Median travel time and flow exposure index plotted against date for daily groups of steelhead leaving Lower Granite Dam, 1998, 2002, and 2003. Dashed horizontal lines are weighted average flow exposure index.



Survival from McNary Dam to John Day Dam

Figure 13. Survival (with standard errors) between the tailraces of McNary and John Day Dams vs. flow (kcfs), water temperature (°C), and turbidity (feet) for PIT-tagged subyearling fall chinook salmon, 1999-2002. Below each survival estimate is the year.

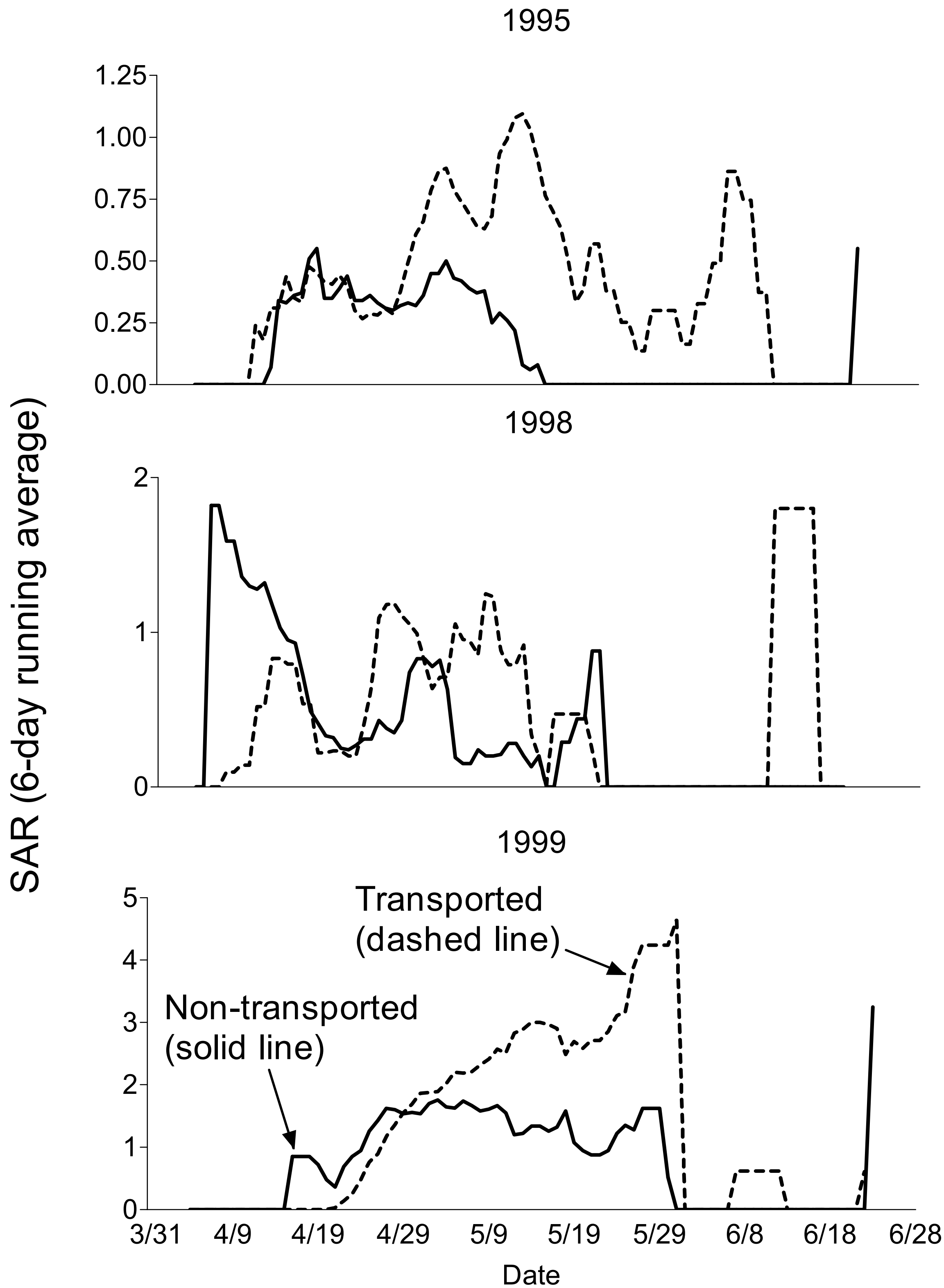


Figure 14. Six-day running average SARs for hatchery spring-summer chinook salmon PIT-tagged and released or transported from Lower Granite Dam.

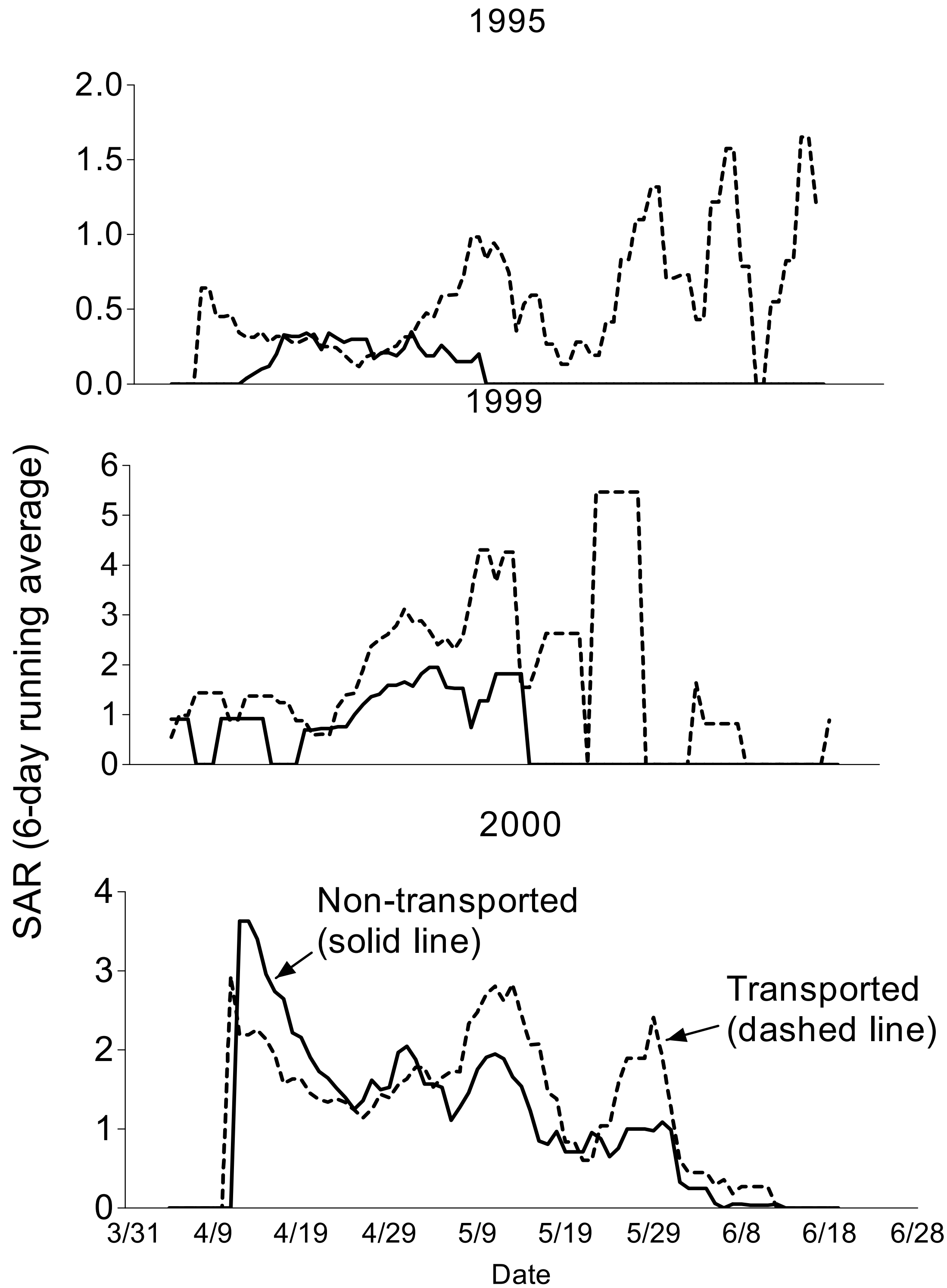


Figure 15. Six-day running average SARs for wild spring-summer chinook salmon PIT-tagged and released or transported from Lower Granite Dam (fish in 2000 transported from Little Goose Dam).

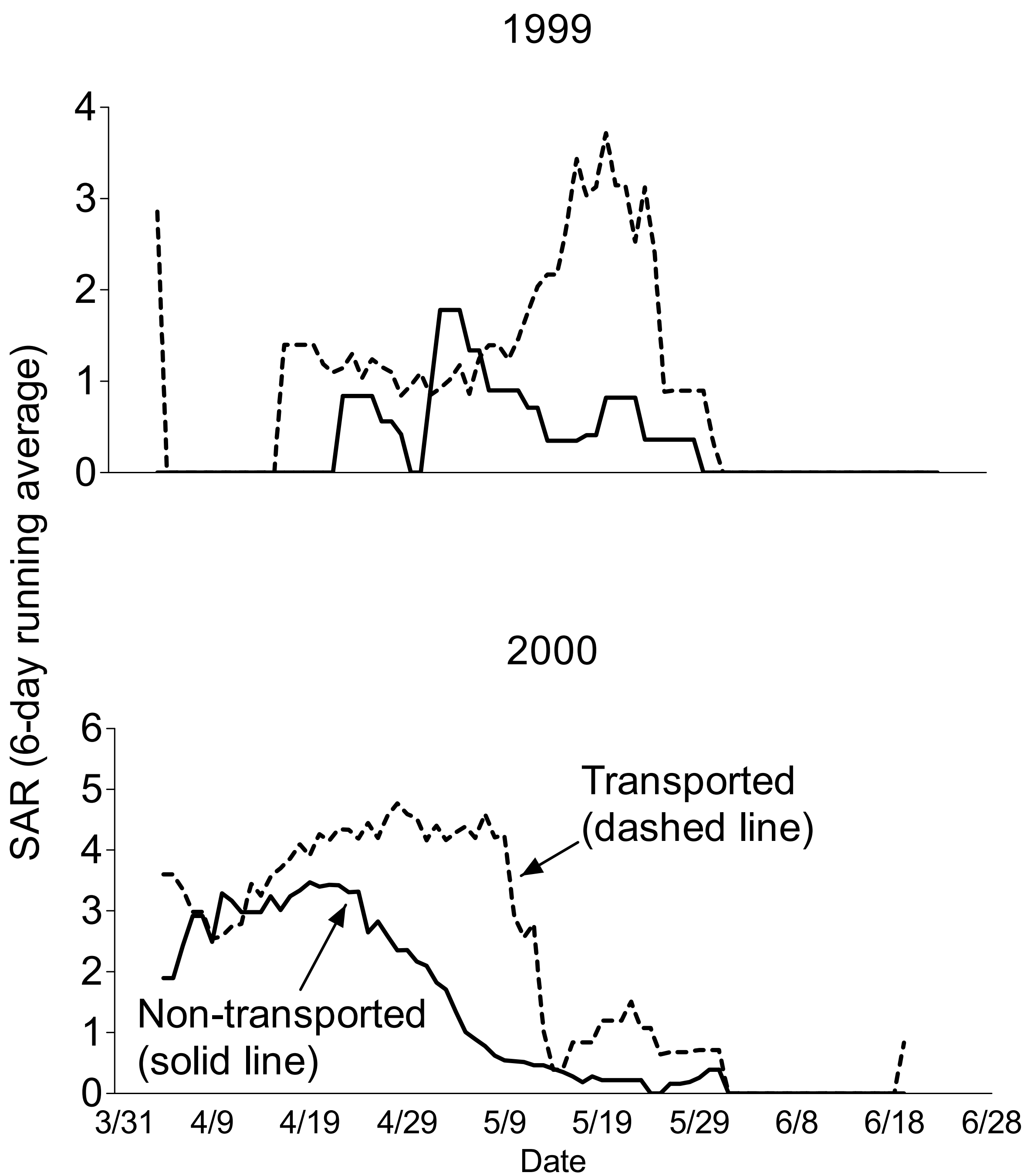


Figure 16. Six-day running average SARs for wild steelhead PIT-tagged and released or transported from Lower Granite Dam (fish transported from Little Goose Dam in 2000).

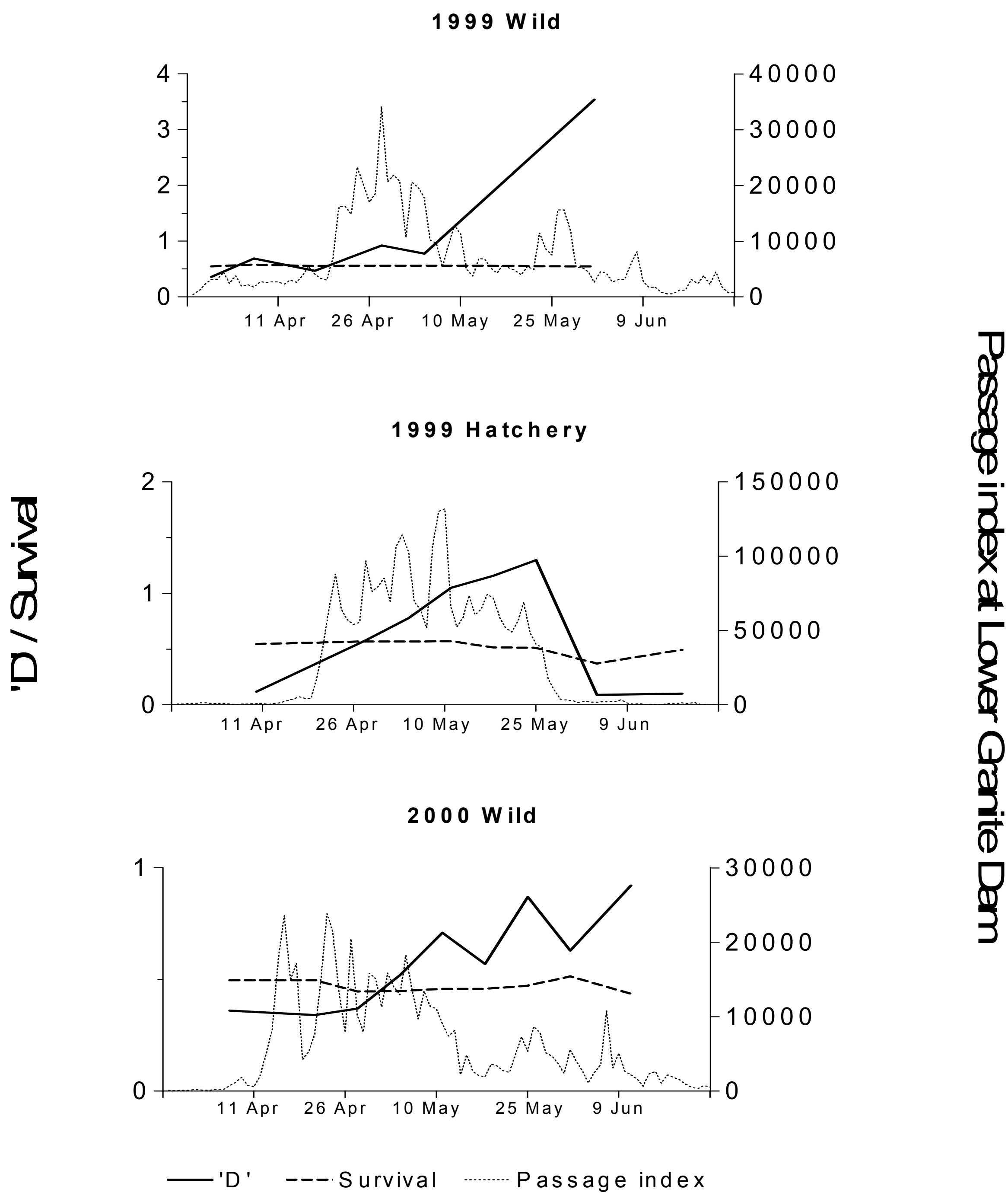


Figure 17. Temporal estimated survival between the tailraces of Lower Granite and Bonneville Dams for Snake River spring-summer chinook salmon, plotted with the temporal D derived from transportation evaluations for fish marked at Lower Granite Dam, 1999-2000.

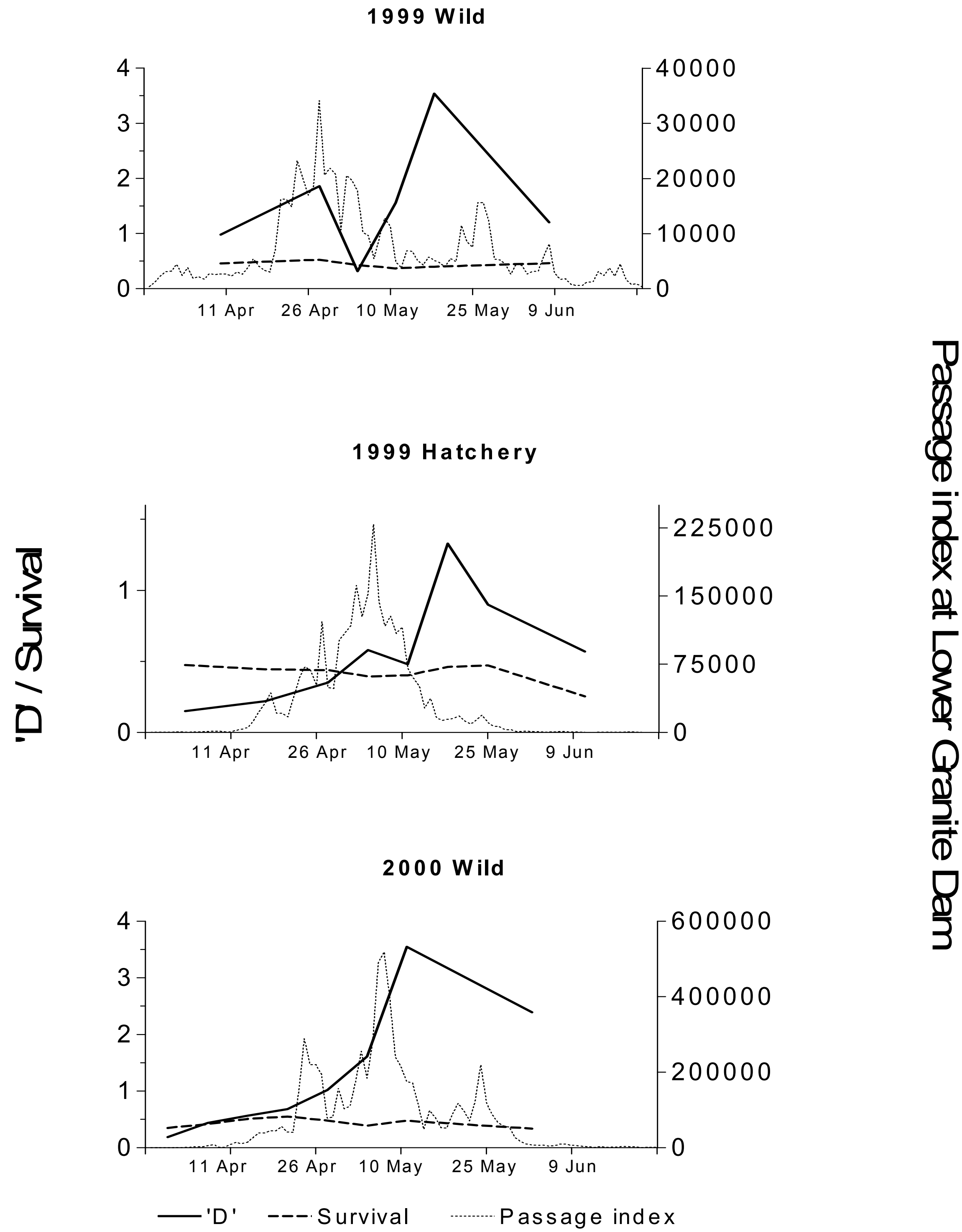


Figure 18. Temporal estimated survival between the tailraces of Lower Granite and Bonneville Dams for Snake River steelhead, plotted with the temporal D derived from transportation evaluations for fish marked at Lower Granite Dam, 1999-2000.

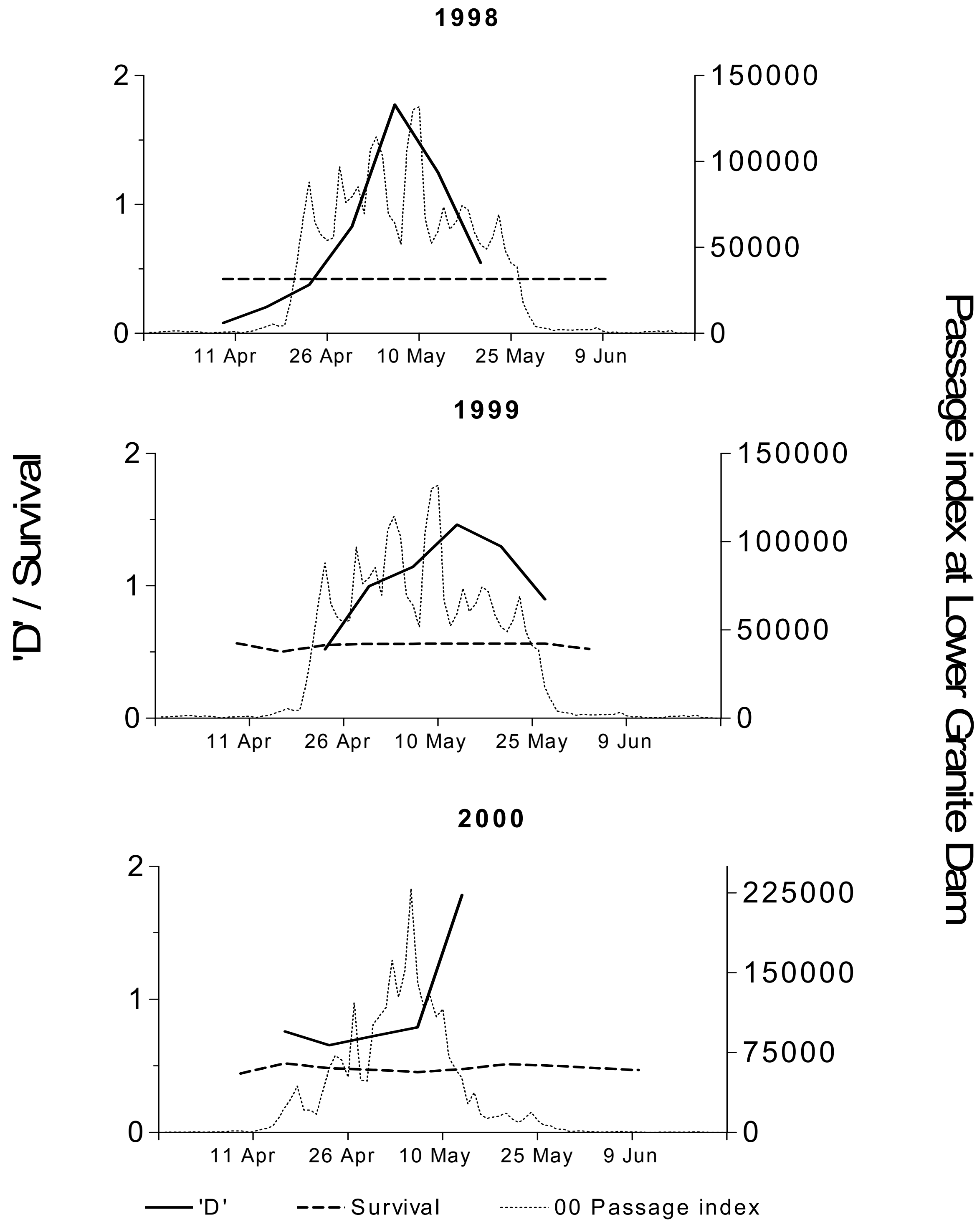


Figure 19. Temporal estimated survival between the tailraces of Lower Granite and Bonneville Dams for Snake River hatchery yearling spring-summer chinook salmon, plotted with the temporal D derived from transportation evaluations for fish marked above Lower Granite Dam, 1998-2000.

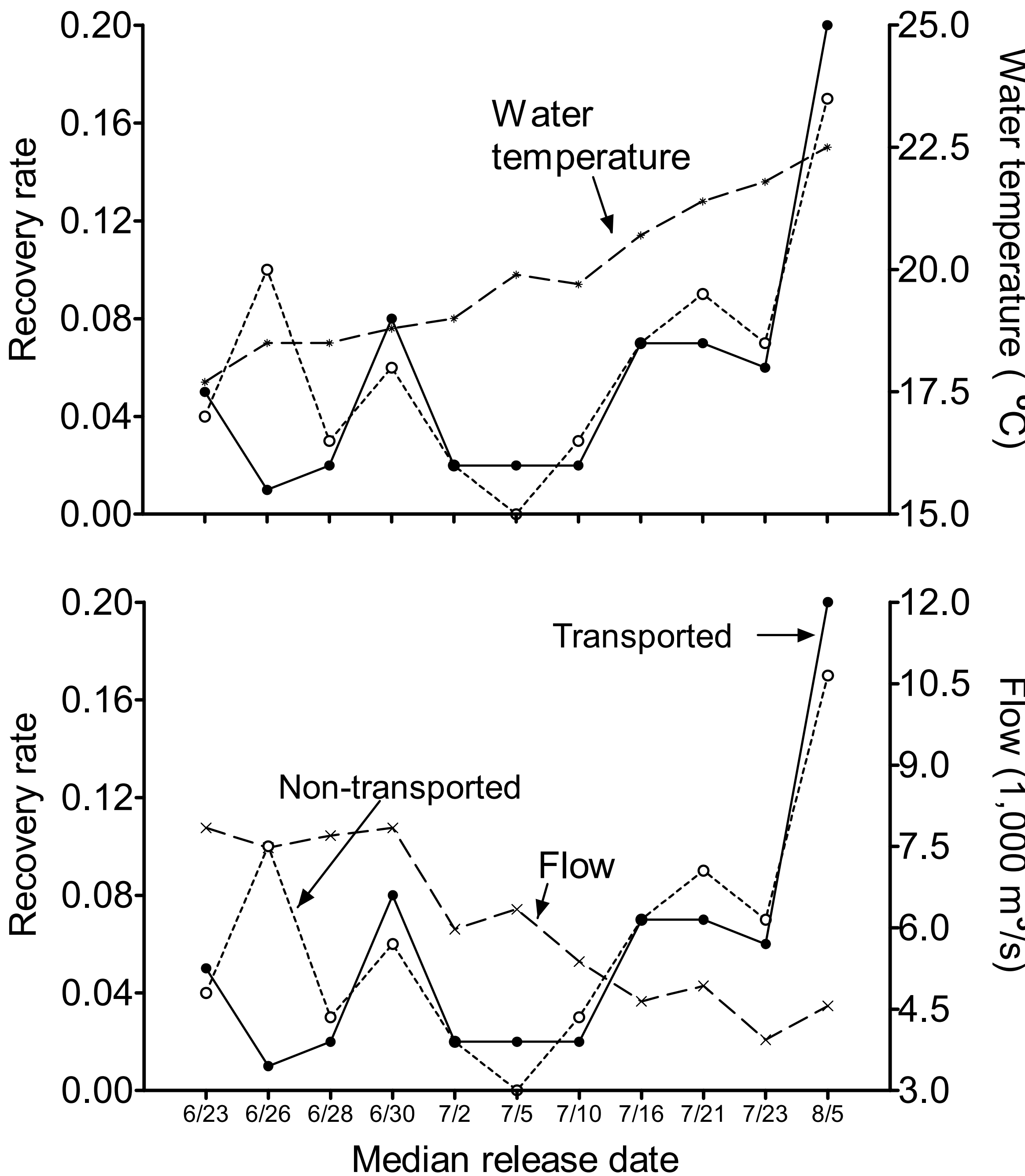


Figure 20. Relative recovery rates of coded-wire tagged (CWT) adult fall chinook salmon recovered from fisheries or at hatcheries from subyearling fall chinook salmon CWT at McNary Dam as juveniles in 1995 and either transported to below Bonneville Dam or released into the tailrace of McNary Dam.

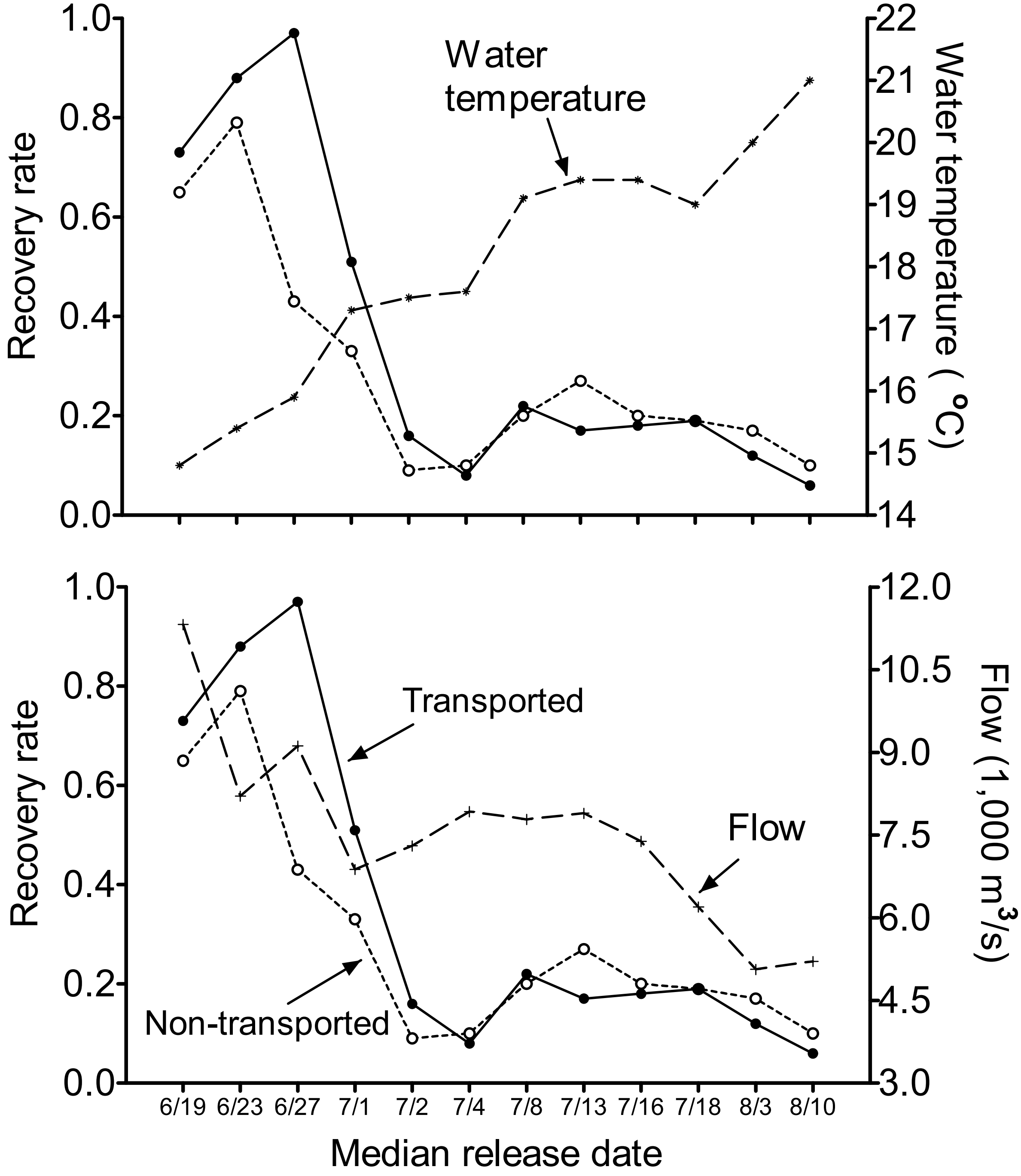


Figure 21. Relative recovery rates of coded-wire tagged (CWT) adult fall chinook salmon recovered from fisheries or at hatcheries from subyearling fall chinook salmon CWT at McNary Dam as juveniles in 1996 and either transported to below Bonneville Dam or released into the tailrace of McNary Dam. .

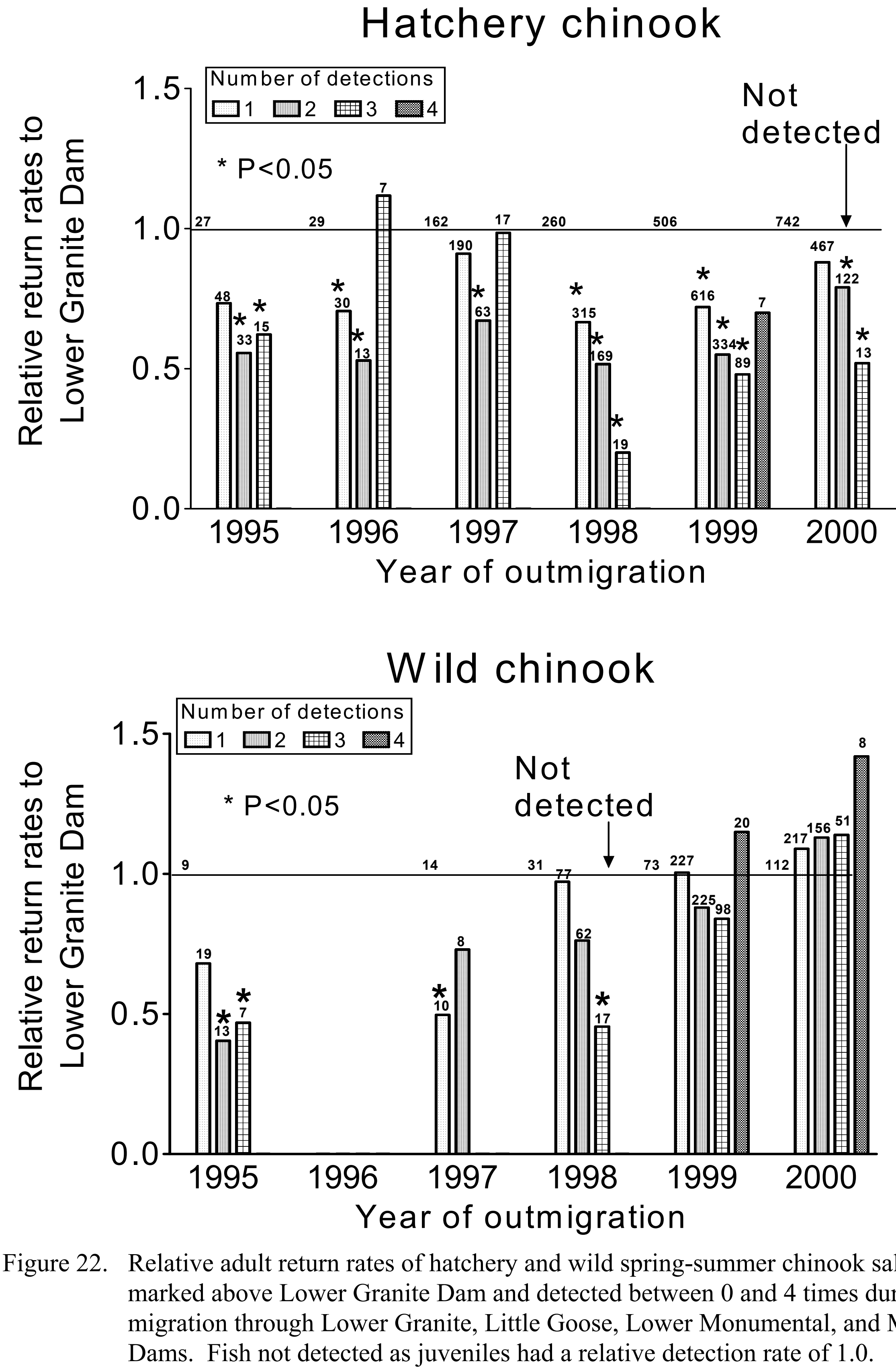


Figure 22. Relative adult return rates of hatchery and wild spring-summer chinook salmon marked above Lower Granite Dam and detected between 0 and 4 times during their migration through Lower Granite, Little Goose, Lower Monumental, and McNary Dams. Fish not detected as juveniles had a relative detection rate of 1.0.

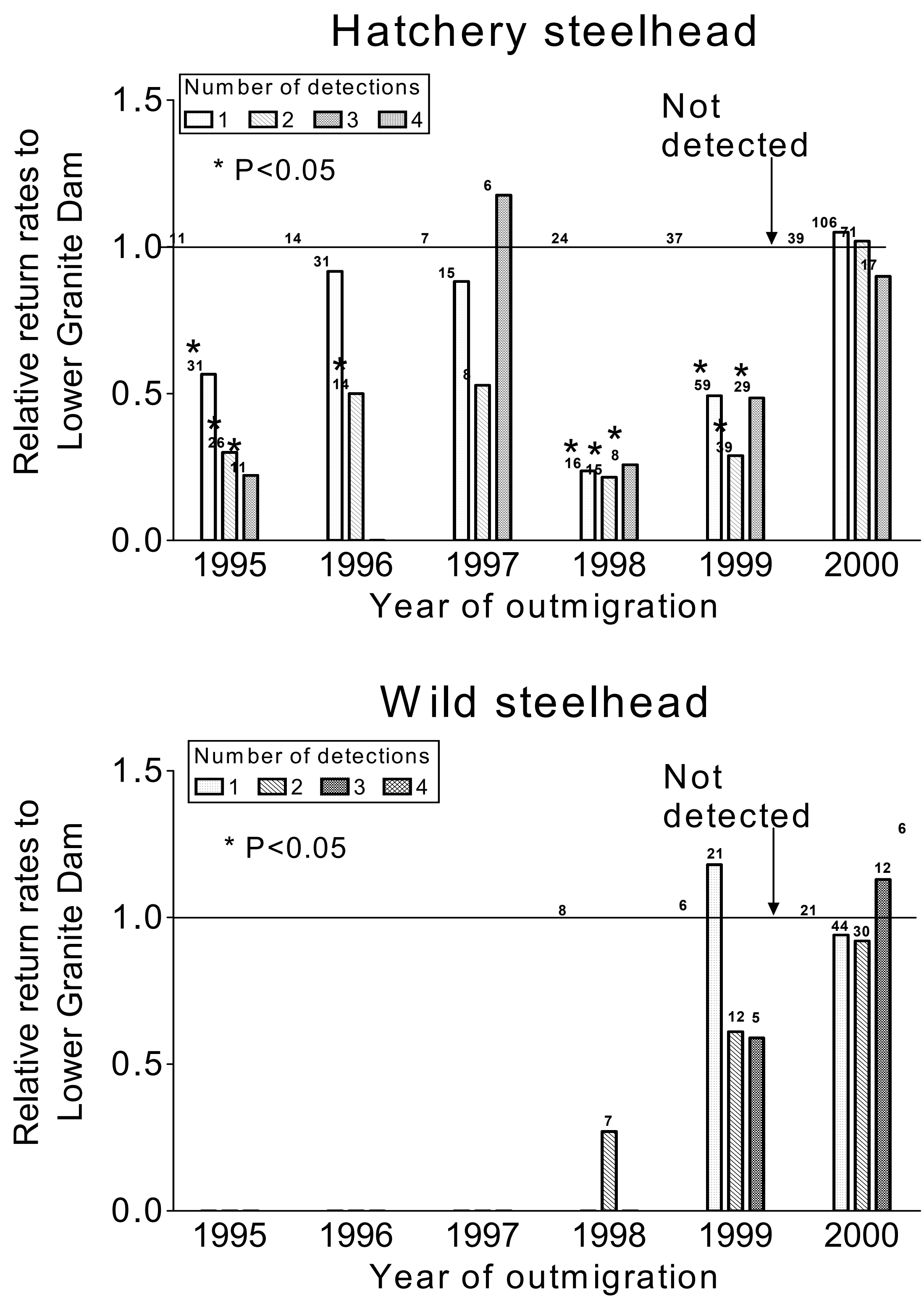


Figure 23. Relative adult return rates of hatchery and wild steelhead marked above Lower Granite Dam and detected 0 to 4 times during their migration through Lower Granite, Little Goose, Lower Monumental, or McNary Dams. Fish not detected as juveniles had a relative detection rate of 1.0.

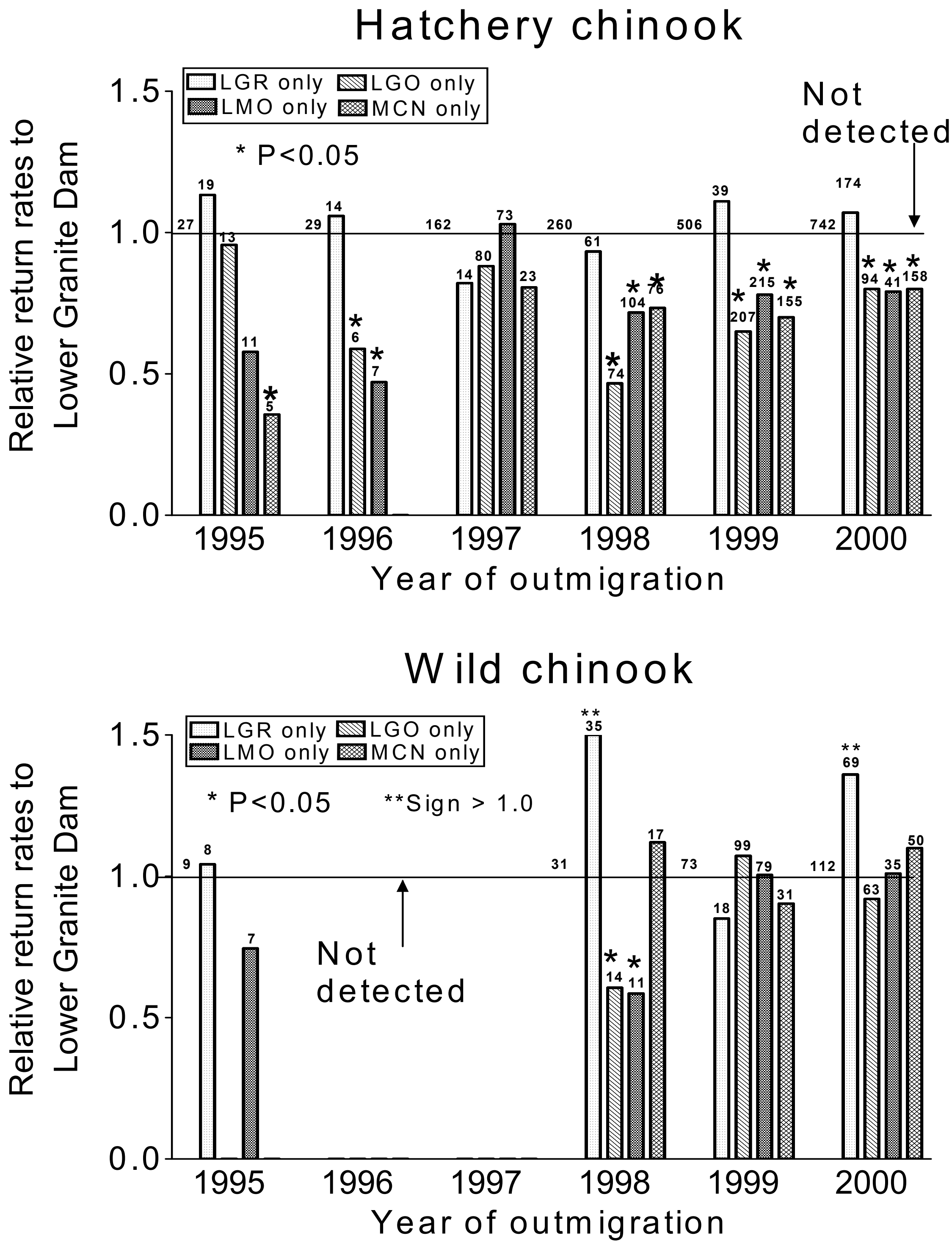


Figure 24. Relative adult return rates of hatchery and wild spring-summer chinook salmon marked above Lower Granite Dam and detected only at Lower Granite, Little Goose, Lower Monumental, or McNary Dam. Fish not detected as juveniles had a relative detection rate of 1.0. **Sign > 1.0 indicates return rate significantly > than the "Not detected" group.

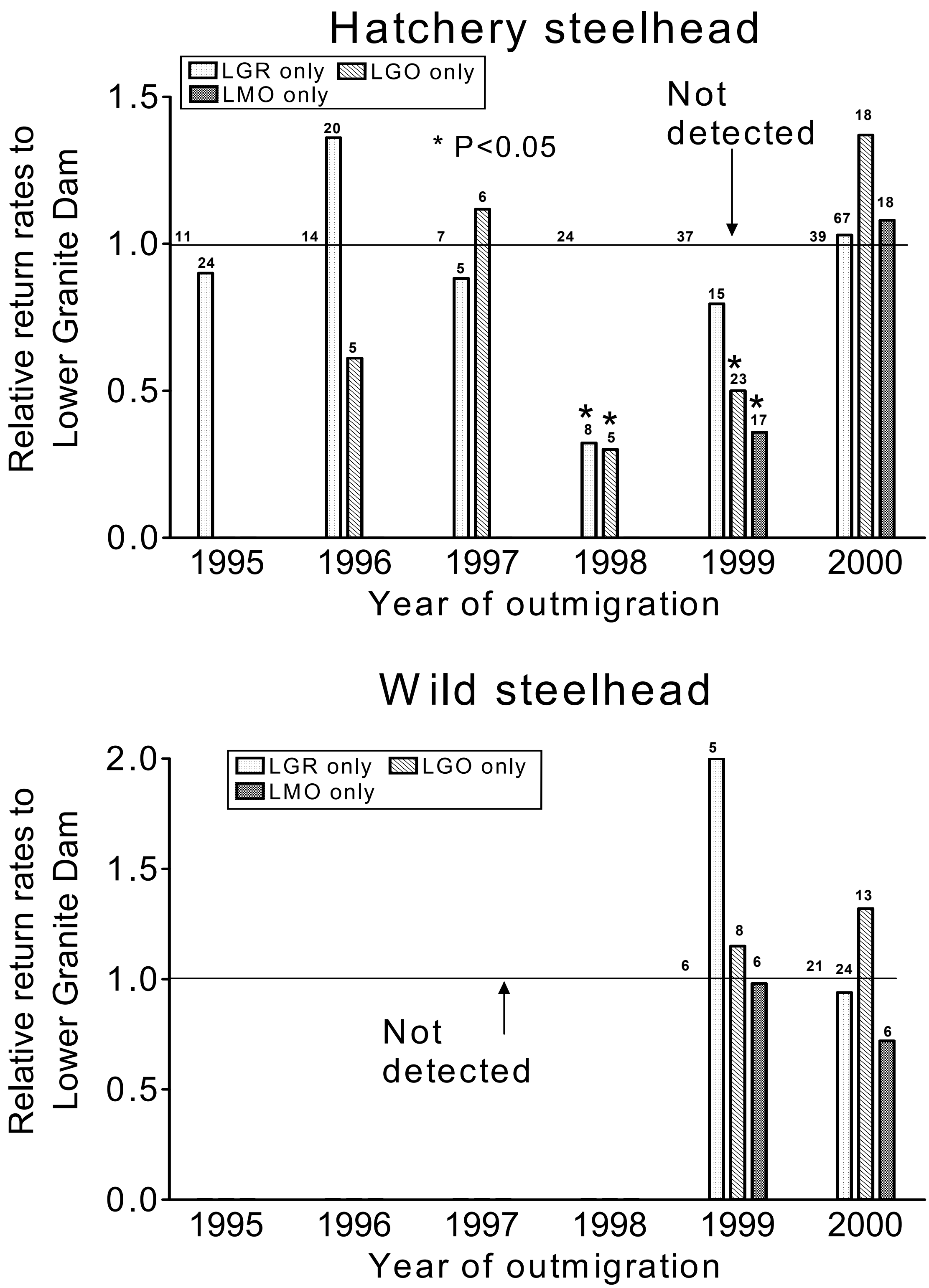


Figure 25. Relative adult return rates of hatchery and wild steelhead marked above Lower Granite Dam and detected only at Lower Granite, Little Goose, Lower Monumental, or McNary Dam. Fish not detected as juveniles had a relative detection rate of 1.0.

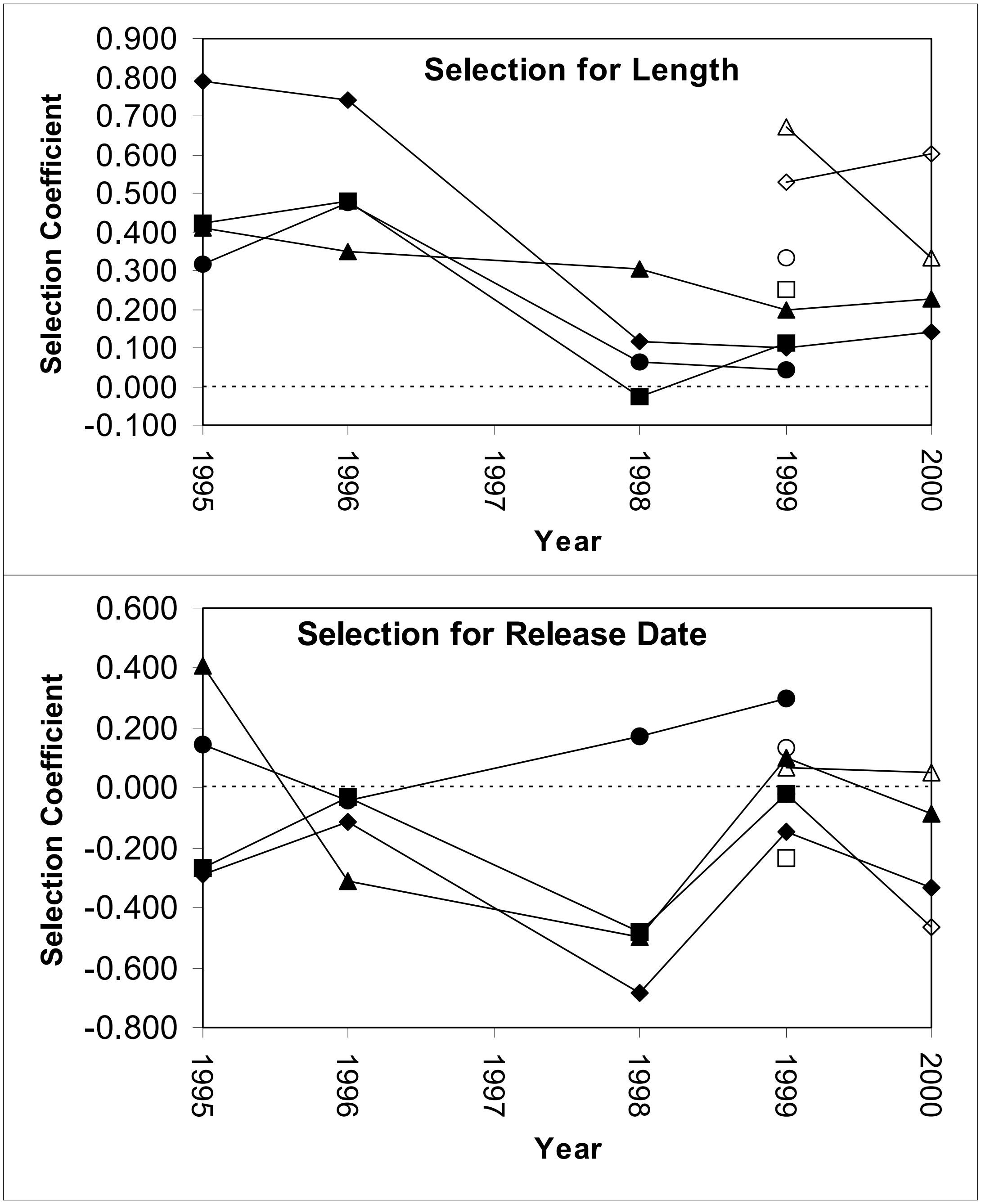


Figure 26. Selection coefficients (see text for details) by year for length at release (top plot) and release date (bottom plot). Abbreviations: Chin – chinook salmon; Steel – steelhead; Inriver – inriver migrants; Transport – transported fish.

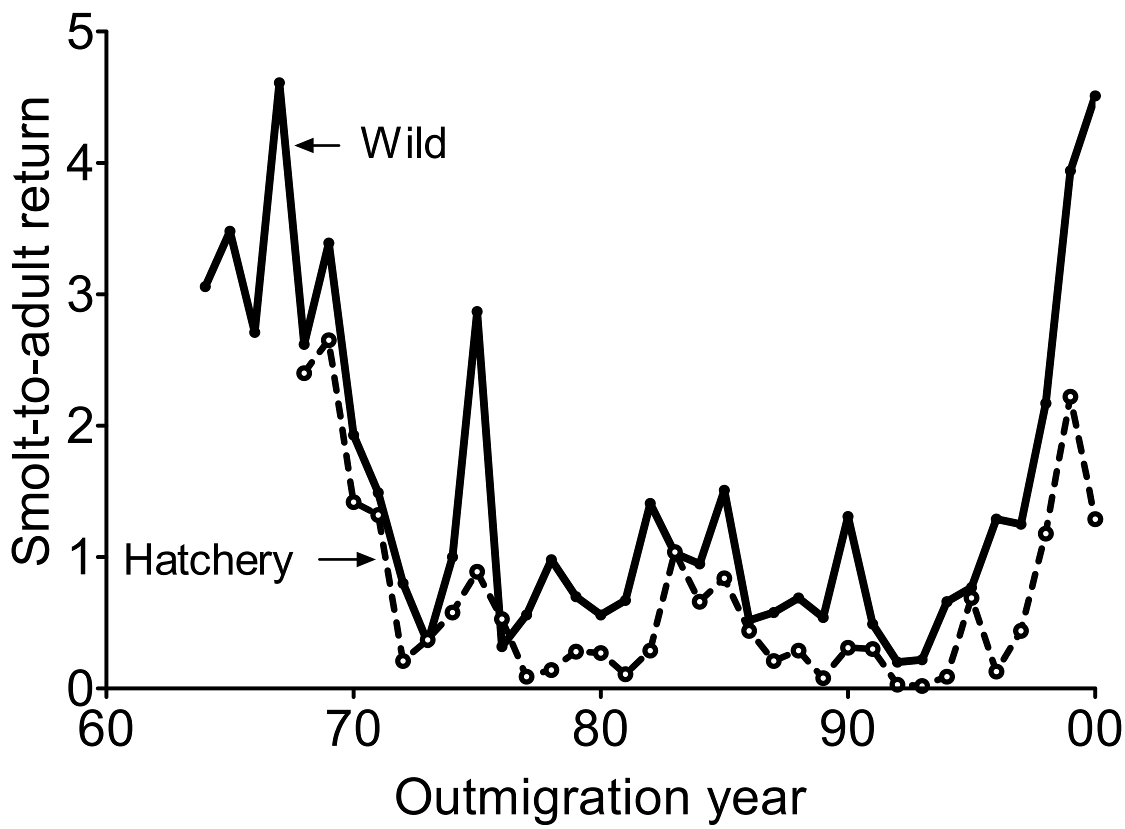


Figure 27. Estimated smolt-to-adult return rates (catch + escapement) of hatchery and wild Snake River spring-summer chinook salmon.

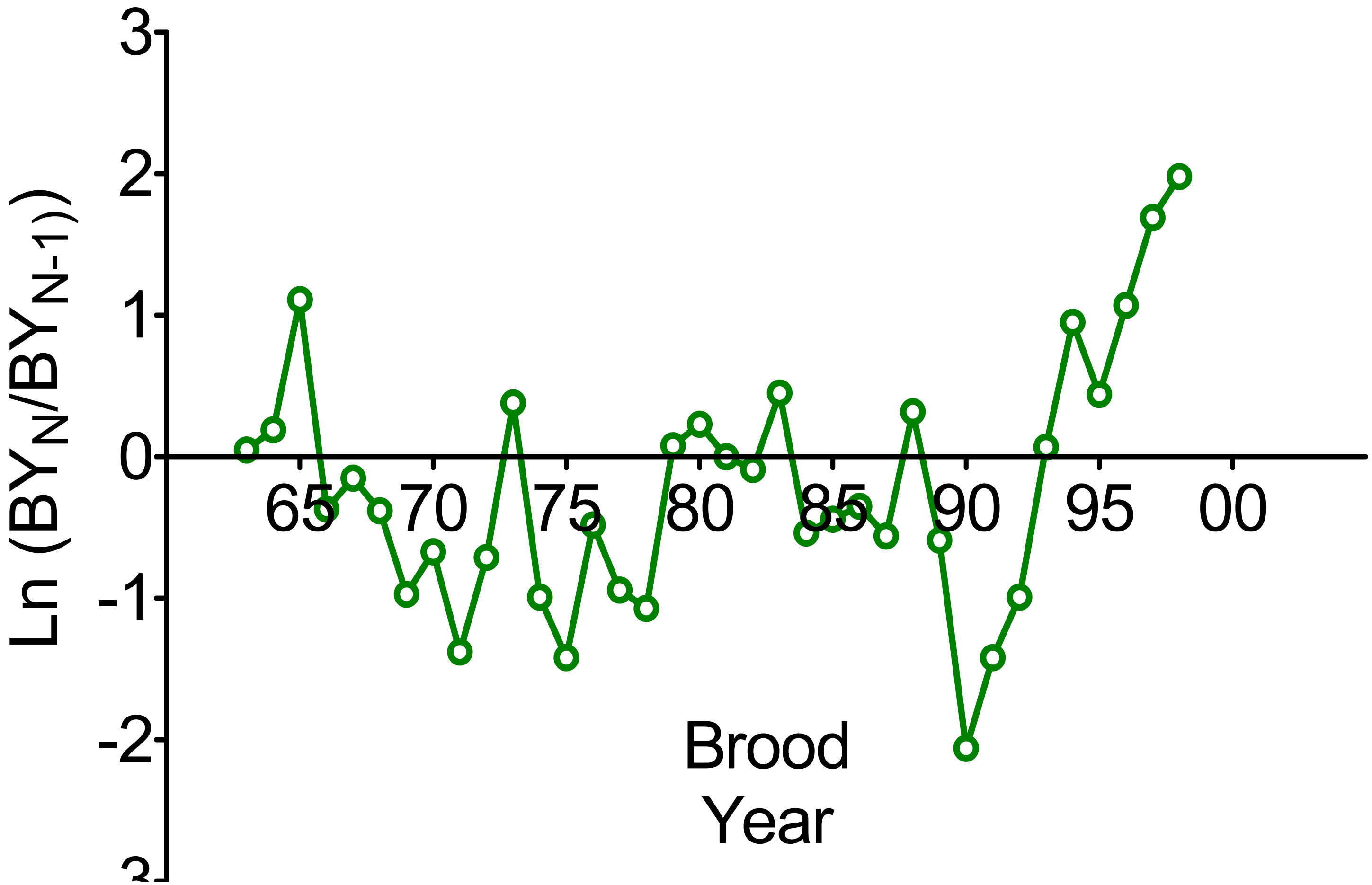


Figure 28. The ln(BY$_N$ = escapement over the upper Snake River dam for the current brood/BY$_{N-1}$ = escapement over the upper Snake River Dam for the brood that produced offspring for current brood) for the composite wild spring-summer chinook salmon population in the Snake River Basin above the upper Snake River Dam (Ice Harbor in 1962, Lower Monumental in 1969, Little Goose in 1970 , and Lower Granite in 1975).

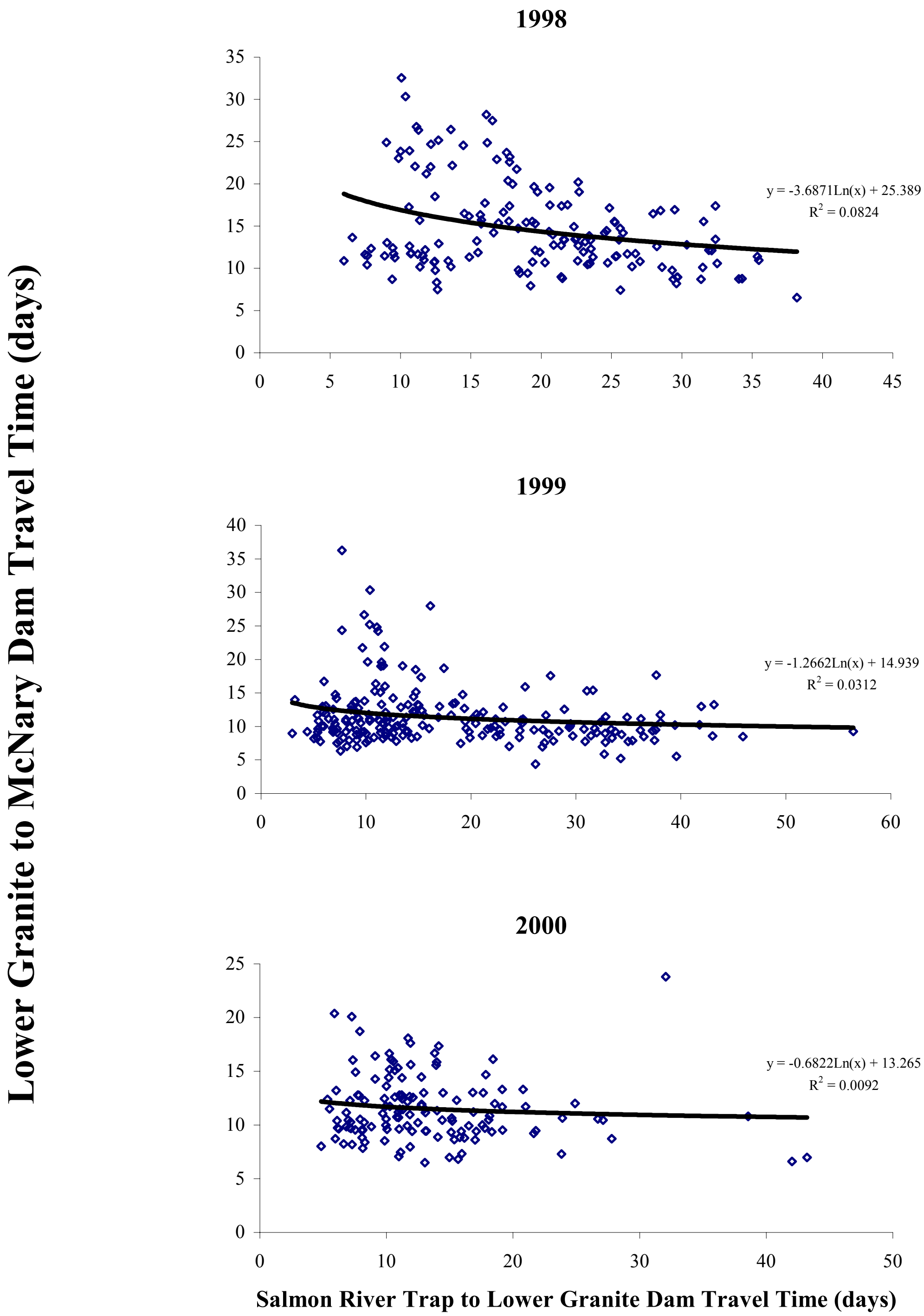


Figure 29. Travel time in days from the Salmon River Trap to Lower Granite Dam plotted against travel time in days from Lower Granite Dam to McNary Dam for PIT-tagged wild yearling chinook salmon from 1998 to 2000.

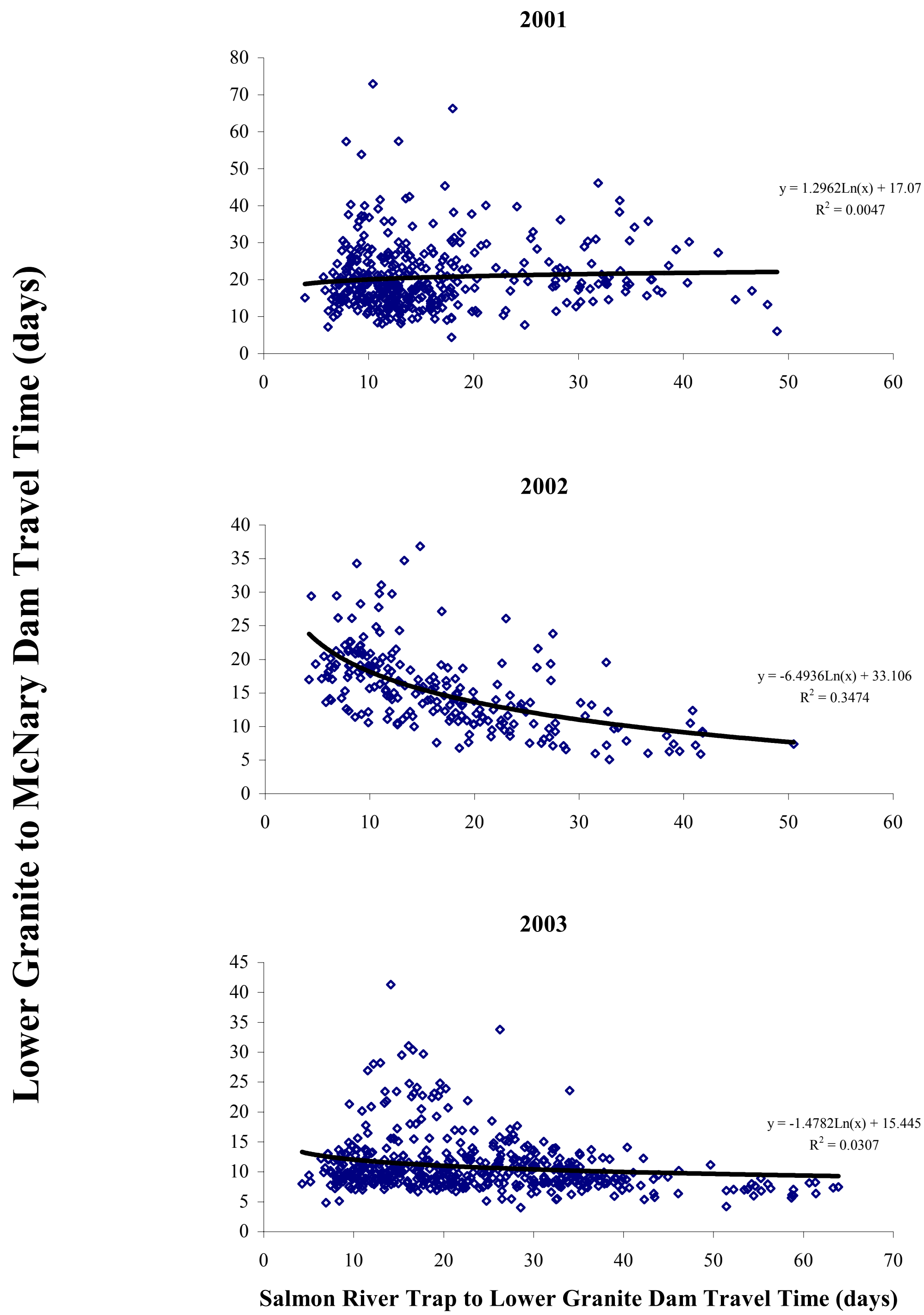


Figure 30. Travel time in days from the Salmon River Trap to Lower Granite Dam plotted against travel time in days from Lower Granite Dam to McNary Dam for PIT-tagged wild yearling chinook salmon from 2001 to 2003.